NINA Norwegian Institute for Nature Research

Monitoring Programme for Terrestrial Ecosystems

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H.C. Pedersen
F. Fossøy

NINA Oppdragsmelding 646

Monitoring Programme for Terrestrial Ecosystems
Report No. 88
Commissioned by: The Directorate for Nature Management
Participating instution: NINA

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Tilgjengelighet: Åpen

Prosjekt nr.: 12720

Ansvarlig signatur:

Pedersen, H.C. & Fossøy, F. 2000. Accumulation of heavy metals in circumpolar willow ptarmigan populations. - NINA Oppdragsmelding 646: 1-31.

Trondheim, August 2000

ISSN 0802-4103
ISBN 82-426-11343

Forvaltningsområde:
Forurensing
Management area:
Pollution

Redaksjon:
Kjetil Bevanger og Lill Lorck Olden

Montering og layout:
Lill Lorck Olden

Sats: NINA•NIKU

Kopiering: Norservice

Opplag: 150

Kontaktadresse:
NINA•NIKU
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N-7485 Trondheim
Telefon: 73 80 14 00
Telefax: 73 80 14 01

Oppdragsgiver:

Direktoratet for naturforvaltning (DN)

Abstract

Pedersen, H.C. & Fossøy, F. 2000. Accumulation of heavy metals in circumpolar willow ptarmigan populations. - NINA Oppdragsmelding 646: 1-31.

The willow ptarmigan is one of the few species with a circumpolar distribution that lives in the arctic-alpine environment throughout the year. As part of the «Arctic Monitoring and Assessment Programme (AMAP)», heavy metals in the liver and kidneys of willow ptarmigan were mapped on a circumpolar scale from 1992 to 1995. The results of the mapping of cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg) and zinc (Zn) from localities in Canada, Norway, Russia and Sweden are presented here, and differences between localities within countries and from one country to another are discussed.

Considerable variations in the Cd content in kidneys and liver of willow ptarmigan were found among localities in both Canada and Scandinavia. The highest median value from one locality was found in Canada, both in liver and kidneys. In Norway, the Cd content is highest in the central mountains of southern Norway and at inland localities in the northern counties of Troms and Finnmark. In an earlier study, 33% (n=273) of the analysed liver samples contained more than 10 mg/kg^{-1}. Here, 53% (n=70) of the analysed kidney samples held more than 70 mg/kg^{-1} Cd.

Willow, a preferred food plant, contains more than 100 times more Cd than, for instance, bilberry. Hence, the Cd content, especially in the liver, very much depends on the amount of willow eaten. This «natural» Cd contamination through intake of willow means that a direct comparison of the Cd levels in willow ptarmigan from different localities cannot reveal the effects of long-range pollution.

The Cd content in central Canada is comparable to that in Scandinavia and Russia, at least for kidneys. However, in both liver and kidneys the median for all the localities in Canada is considerably higher than for the other countries. A total of 32% (n=75) of the liver samples had a Cd content above 30 mg/kg^{-1}, whereas 92% (n=75) of the kidney samples held more than 40 mg/kg^{-1}. Furthermore, the level was exceptionally high in some localities, several birds having more than 50 mg/kg^{-1} in their liver and more than 400 mg/kg^{-1} in their kidneys.

It is difficult to evaluate regional differences in Sweden, but most localities have the same Cd level as the more moderately contaminated ones in Norway. No liver samples were found to have a higher Cd content than 30 mg/kg^{-1}, but 32% (n=38) contained more than 10 mg/kg^{-1}. However, 93% (n=41) of the kidney samples held more than 40 mg/kg^{-1}.

The data from Russia show Cd levels comparable to moderately Cd-contaminated localities in Canada, Norway and Sweden. Lack of data makes it impossible to trace any regional differences in the Cd level. The Cd content in 18% (n=11) of the liver samples was in excess of 10 mg/kg^{-1}, whereas 64% (n=11) of the kidney samples held more than 40 mg/kg^{-1}.

Significant variations are found in the Pb concentration in kidneys and liver of willow ptarmigan among the localities in Norway and Canada, but not so in Sweden and Russia. The levels in Sweden and Russia are comparable to those in Canada and to low-level samples in Norway. The highest median value from all the localities is found in Norway, both in liver and kidneys. The highest Pb content is found in southern Norway, indicating an effect of long-range pollution. Western Canada has a significantly higher level than central Canada.

Hg levels vary significantly among localities within all the countries for liver samples and within all except Sweden for kidney samples. In Scandinavia, there is no distinct regional pattern, as is found for Pb. Canadian samples from both tissues reveal a significantly higher Hg level in central than western parts, which is the opposite of the patterns shown by Cd and Pb.

For Cu and Zn, significant variations were found in liver and kidneys among localities in Canada and Norway, whereas the variation was only significant in kidneys in samples from Sweden. Comparison between western and central Canada reveals only a significant difference for Cu in liver, more being found in central Canada. There are no prominent regional differences either among or within countries, although some localities in Canada seem to have a higher Cu concentration in kidneys than is found in Scandinavia and Russia.

Key words: Terrestrial environment - circumpolar mapping - willow ptarmigan - Cd - Pb - Hg - Cu - Zn - AMAP - *Lagopus lagopus*

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Referat

Pedersen, H.C. & Fossøy, F. 2000. Akkumulering av tungmetaller i sirkumpolare lirypebestander. - NINA Oppdragsmelding 646: 1-31.

Lirypa er en av svært få arter som har en sirkumpolar utbredelse og som lever i det arktisk-alpine økosystemet gjennom hele året. Som delprosjekt under "Arctic Monitoring and Assessment Programme (AMAP)" ble det i 1992 til 1995 foretatt en sirkumpolar kartlegging av tungmetaller i lever og nyre fra lirype. Her presenteres resultatene for kadmium (Cd), kobber (Cu), bly (Pb), kvikksølv (Hg) og sink (Zn) fra samtlige lokaliteter.

Det ble funnet relativt stor variasjon i Cd-innhold i lever og nyre fra ryper fra forskjellige lokaliteter både i Canada og Skandinavia. Den høyeste verdien fra en lokalitet ble funnet i Canada, både i lever og nyre. I Norge ble det funnet at Cd-innholdet er høyest i lokaliteter fra sentrale høyfjellsområder i Sør-Norge og fra innlandslokaliteter i Troms og Finnmark.

I en tidligere undersøkelse hadde 33 % (n=273) av de analyserte lever-prøvene et Cd-innhold over 10 mg kg^{-1}. I denne undersøkelsen fant vi at 53 % (n=70) av de analyserte nyre-prøvene hadde et Cd-innhold over 70 mg kg^{-1}.

I vier er det mer enn 100 ganger høyere Cd-innhold enn f.eks i blåbær. Dette fører til at Cd-innholdet, spesielt i lever, er svært avhengig av hvor mye vier lirypa til enhver tid spiser. På grunn av "naturlig" forurensning av Cd gjennom inntak av vier vil ikke denne undersøkelsen, gjennom en direkte sammenligning av ryper fra forskjellige områder, kunne påvise langtransportert forurensning.

Cd-innholdet i liryper fra midt-Canada er på samme nivå som i Skandinavia og Russland. Imidlertid er gjennomsnitts-nivået totalt sett for Canada vesentlig høyere, både i lever og nyre, sammenlignet med de andre landene. Totalt 32 % (n=75) av lever-prøvene fra Canada har et Cd-innhold over 30 mg kg^{-1}, og totalt 92 % (n=75) av nyre-prøvene har et Cd-innhold over 40 mg kg^{-1}. Fra enkelte lokaliteter var Cd-innholdet eksepsjonelt høyt med verdier over 50 mg kg^{-1} i lever og over 400 mg kg^{-1} i nyre.

Det er vanskelig å påvise regionale forskjeller på grunnlag av resultatene fra Sverige, men de fleste lokalitetene har samme Cd-nivå som de mer moderat "forurensede" lokalitetene i Norge. Vi har ingen lever-prøver med Cd-nivå over 30 mg kg^{-1}, mens 32 % (n=38) av prøvene har over 10 mg kg^{-1}. I nyre-prøvene har 93 % (n=41) et Cd-nivå over 40 mg kg^{-1}.

Cd-nivået i prøvene fra Russland kan sammenlignes med moderat Cd-kontaminerte lokaliteter i Canada, Norge og Sverige. Lite data gjør at det ikke er mulig å påvise eventuelle regionale forskjeller i Cd-nivået. I lever-prøvene har 18 % (n=11) et Cd-innhold over 10 mg kg^{-1}, mens 64 % (n=11) av nyre-prøvene har over 40 mg kg^{-1}.

Det ble funnet stor variasjon i Pb-innhold i lever og nyre fra liryper fra forskjellige lokaliteter i Norge og Canada, men ikke mellom lokaliteter i Sverige og Russland. Nivået som ble funnet i Sverige og Russland er på linje med nivået som ble funnet i Canada og lokaliteter med lavt Pb-nivå fra Norge. Det høyeste nivået totalt sett i alle lokaliteter og land ble funnet i Norge, både for lever og nyre. Høyest Pb-nivå ble funnet i de sørligste lokalitetene i Norge, og dette indikerer en effekt av langtransportert forurensning. I Canada var det signifikant høyere Pb-nivå i vestlige lokaliteter i forhold til lokaliteter i midt-Canada.

Det ble funnet en tydelig variasjon i Hg-innhold mellom lokaliteter i lever-prøver fra alle land og i nyre-prøver fra alle land untatt Sverige. I Skandinavia ble det ikke funnet noe klart regionalt mønster slik som for Pb. Resultatene fra Canada viste klart høyere Hg-nivå i både lever- og nyre-prøver fra midt-Canada i forhold til vestlige lokaliteter, noe som er motsatt av mønsteret som ble funnet for Cd og Pb.

Det ble funnet en signifikant variasjon mellom lokaliteter for Cu og Zn i så vel lever som nyre i Canada og Norge, mens denne variasjonen bare ble funnet i nyre-prøver fra Sverige. En sammenligning mellom vest- og midt-Canada gir en signifikant forskjell bare for Cu i lever-prøver, og de høyeste verdiene ble funnet i midt-Canada. Det ble ikke funnet noen klare regionale forskjeller verken mellom eller innen land, men det ser allikevel ut som om enkelte lokaliteter i Canada har høyere Cu-nivå i nyre-prøver i forhold til Skandinavia og Russland.

Emneord: Terrestrisk miljø – sirkumpolar kartlegging - lirype - Cd - Pb - Hg- Cu - Zn - AMAP - *Lagopus lagopus*

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Preface

In 1994, the Norwegian Institute for Nature Research (NINA) was given funding to carry out a circumpolar study on heavy metals in willow ptarmigan. The study began while the first author was visiting the University of Alberta, Canada, as an NSERC Fellow in 1992 and gained access to willow ptarmigan collected in Chilkat Pass, northern British Columbia. At that time, we were also carrying out a major survey of heavy metals in willow ptarmigan from 77 localities in Norway. Birgit Braune from the Canadian Wildlife Service had started a survey of waterfowl in eastern Canada and was also planning to include localities from throughout Canada during the following years. She also planned to collect some species of game birds and agreed to provide us with samples from willow ptarmigan. In 1994 and 1995, samples were also collected from Sweden and Russia. So far, samples and data are lacking from Alaska and Finland.

The project became part of the international «Arctic Monitoring and Assessment Programme (AMAP)» in 1993, but has been funded through the «Monitoring Programme for Terrestrial Ecosystems» run by the Directorate for Nature Management (DN).

A great number of people have assisted in collecting willow ptarmigan and we would especially like to thank B. Braune, S.J. Hannon (Canada), J.T. Braa, H. Collin, T. Frisk, D.H. Karlsen, J.B. Steen (Sweden) and E. Finnstad (Russia). S. Pedersen has prepared the tissue samples and S. Lierhagen has been responsible for the chemical analyses. I would like to thank John Atle Kålås for allowing me to use unpublished material from Norway. I am also grateful to Signe Nybø for comments and Richard Binns for checking the language of this report.

Trondheim, May 2000

Hans Chr. Pedersen

Contens

1 Introduction

For several decades, southern Norway has been affected by long-range atmospheric transport of heavy metals from central Europe (Steinnes 1987, Steinnes et al. 1989). Due to this and the observed effects of acid precipitation in Norway, the Directorate for Nature Management (DN) started a «Monitoring Programme for Terrestrial Ecosystems» in 1990. A number of ecosystems were monitored, one of the main ones being the arctic-alpine ecosystem (Løbersli 1989).

Previous studies have shown elevated levels of cadmium (Cd) and lead (Pb) in various game species in southern Norway (Frøslie et al. 1986, Fimreite et al. 1990, Kålås & Lierhagen 1992). The highest levels have been found in rock ptarmigan *Lagopus mutus* and willow ptarmigan *Lagopus l. lagopus*. As the willow ptarmigan is one of the key species in the arctic-alpine ecosystem, having a profound effect on several other species and a wide distribution, in addition to being one of the most important game species in Norway, it was chosen as one to be monitored.

Several studies have shown that elevated levels of heavy metals may give lethal and sub-lethal effects in both birds and mammals. Known effects include reduced growth, anaemia, kidney lesions, testicular damage and behavioural effects (Sarkar & Mondal 1973, Richardson et al.1974, Cain et al. 1983, Wren 1983, Eisler 1985, 1987, 1988a, b, Scheuhammer 1987, 1991, McBee & Bickham 1991). To map the incidence of different heavy metals in small game species (mountain hare, black grouse and willow ptarmigan), a countrywide survey was carried out in 1990-91 (Kålås & Lierhagen 1992). No abnormal levels of copper (Cu), zinc (Zn) or mercury (Hg) were found in willow ptarmigan. Considerable variations were found between localities for both cadmium (Cd) and lead (Pb). However, whereas Pb, as expected, showed a clear regional pattern, the highest concentrations being in the southernmost areas (Kålås et al. 2000), Cd did not show such a pattern (Kålås & Lierhagen 1992).

The willow ptarmigan, along with the reindeer (caribou), is one of the very few species with a circumpolar distribution that lives in the arctic-alpine environment throughout the year. Like the reindeer (caribou), the willow ptarmigan is very suitable for mapping heavy metal loading in a key herbivore species in this ecosystem. To be able to survey the state of health of this vulnerable environment, it is important not only to analyse snow samples and determine the chemistry of precipitation, but also to study the biotic components.

As part of the international «Arctic Monitoring and Assessment Programme (AMAP)», circumpolar mapping of heavy metals in liver and kidneys of willow ptarmigan started in 1992. This report presents the results of the mapping of cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg) and zinc (Zn) from localities in Canada, Norway, Russia and Sweden.

2 Material and Methods

2.1 Age of birds

Earlier studies have shown that accumulation of Cd is highly age-dependent (Flick et al. 1971, NRCC 1979). In accordance with this, age-specific differences in Cd content have also been found in willow ptarmigan (Fimreite et al. 1990, Pedersen & Myklebust 1993). However, the age-dependent accumulation of Cd in willow ptarmigan seems to reach a threshold value during their first year of life (Pedersen & Myklebust 1993, Myklebust & Pedersen 1999). Juvenile ptarmigan shot from late-winter onwards contain more or less the same quantity of Cd as adult birds, and at least in kidneys, no major changes in the Cd content seem to occur from one season to another (Pedersen & Myklebust 1993, Myklebust & Pedersen 1999). To allow comparison between areas, adult birds shot during autumn and winter have mainly been used in the present study. However, in some areas in Canada adult birds shot during other seasons have also been used. To increase the sample size, a few juveniles from Canada (Chilkat Pass) and Sweden (Gäddede), shot in late winter and spring, have been included.

2.2 Study areas

Norway
During 1990-91, a countrywide survey of heavy metal loading was carried out in small game in Norway. Willow ptarmigan were collected from 77 localities and the results of liver analyses were reported (Kålås & Lierhagen 1992). For this report, data from 15 localities have been selected using the criteria: 1) sample size $\geq$ 5 adult birds (fulfilled in 13 localities), and 2) localities in different parts of Norway (**Figure 1, Table 1**). The results of kidney analyses are also presented here.

Sweden
Willow ptarmigan were collected at six localities in Sweden during the autumn and winter of 1994-95 (**Figure 2, Table 2**). We were able to collect 10 birds at three localities, 6 at one locality, and only 3 and 2, respectively, at the last two localities. Dr. Torsten Mörner, Swedish Veterinary Institute, Uppsala, collected willow ptarmigan from three additional localities in 1989-1994. The intention was to use this material here, but fund-raising problems have meant that only the material from the six localities sampled in 1994-95 can be presented here.

Canada
In 1992, liver and kidneys were collected from 29 willow ptarmigan from Chilkat Pass in north-west British Columbia. The birds were collected from 1985 to 1988 by Dr. Susan J. Hannon, University of Alberta, for various purposes (e.g. Hannon & Martin 1992) and stored frozen (-20° C). In addition, from 1992 to 1994, willow ptarmigan were collected by Dr. Birgit Braune, Canadian Wildlife Service, from 8 localities in arctic Canada (**Figure 3, Table 3**). We tried to get at least five birds from each

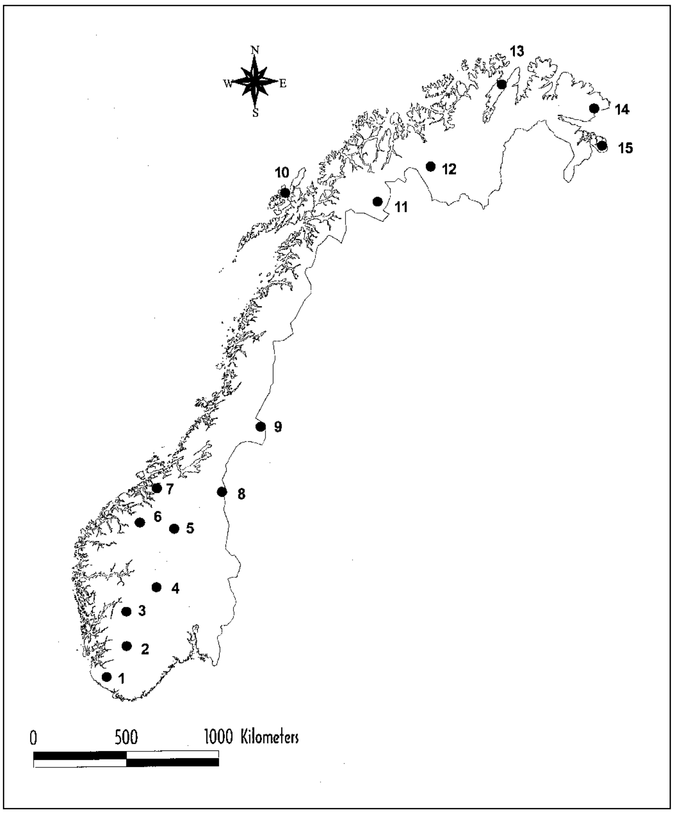

Figure 1. *Map with localities in Norway. Numbers in map correspond with numbers in* ***table 1****. – Kart som viser innsamlingslokaliteter i Norge. Tallene på kartet korresponderer med tall i* ***tabell 1****.*

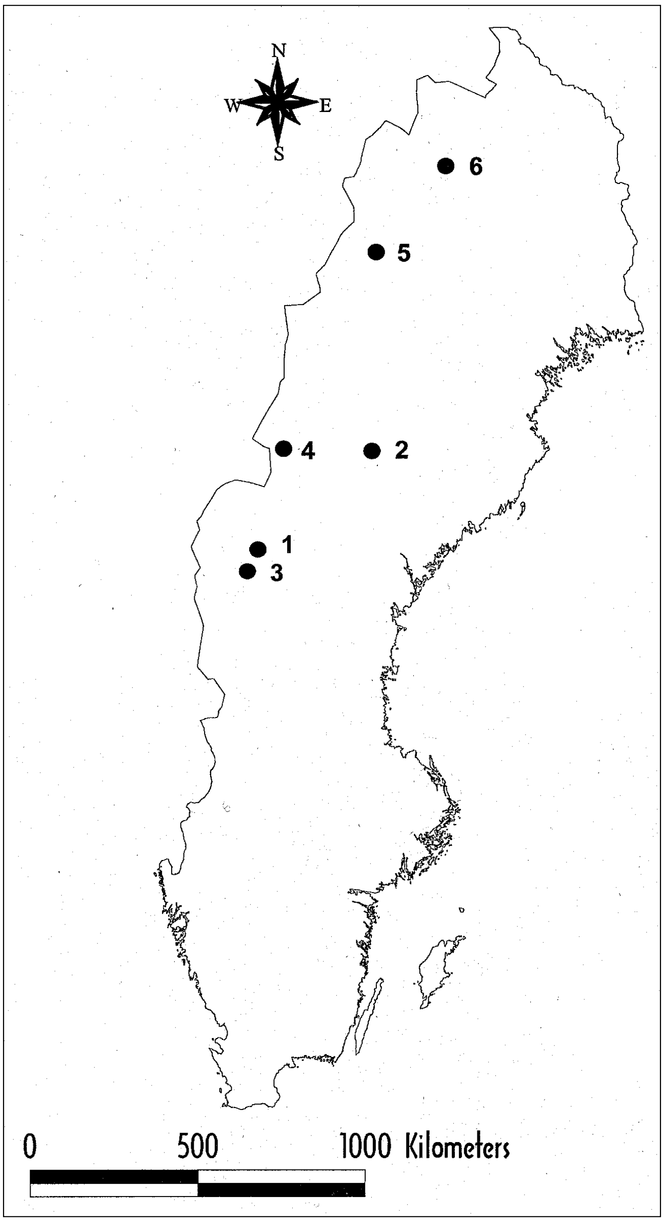

Figure 2. *(To the right.) Map with localities in Sweden. Numbers in map correspond with numbers in* ***table 2****. - Kart som viser innsamlingslokaliteter i Sverige. Tallene på kartet korresponderer med tall i* ***tabell 2****.*

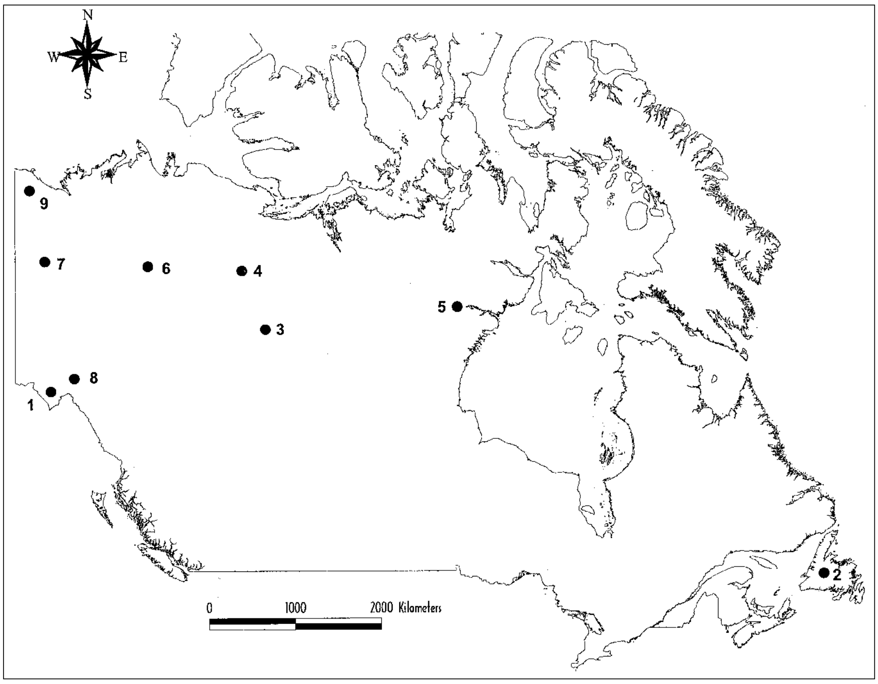

Figure 3. *Map with localities in Canada. Numbers in map correspond with numbers in* ***table 3****. - Kart som viser innsamlingslokaliteter i Canada. Tallene på kartet korresponderer med tall i* ***tabell 3****.*

Table 1. Sampling localities of Norway (1-15) and number of willow ptarmigan collected at each locality. - Lokaliteter for innsamling av lirype i Norge (1-15) og antall ryper samlet inn fra hver lokalitet.

Locality no./ Lokalitets nr.	Name/ Stedsnavn	County/ Fylke	Locality/ Lokalitet	No. birds/ Antall liryper
1	Lund	Rogaland	58°30'N 06°30'E	9
2	Bykle	Aust-Agder	59°20'N 07°20'E	6
3	Eidfjord	Hordaland	60°30'N 07°00'E	5
4	Hemsedal	Buskerud	60°50'N 08°40'E	5
5	Kongsvoll	Sør-Trøndelag	62°20'N 09°40'E	8
6	Nesset, Eikesdal	Møre og Romsdal	61°50'N 10°10'E	5
7	Rindal	Møre og Romsdal	63°00'N 09°10'E	4
8	Selbu	Sør-Trøndelag	63°10'N 11°00'E	10
9	Lierne	Nord-Trøndelag	64°30'N 13°30'E	5
10	Øksnes	Nordland	68°50'N 15°30'E	4
11	Dividalen	Troms	68°50'N 19°30'E	5
12	Kautokeino	Finnmark	69°00'N 23°00'E	5
13	Porsanger, Tamsøy	Finnmark	70°50'N 25°40'E	5
14	Skallelv, Nord-Varanger	Finnmark	70°10'N 30°20'E	5
15	Jarfjord	Finnmark	69°40'N 30°30'E	6

Table 2. Sampling localities of Sweden (1-6) and number of willow ptarmigan collected at each locality. - Lokaliteter for innsamling av lirype i Sverige (1-6) og antall ryper samlet inn fra hver lokalitet.

Locality no./ Lokalitets nr.	Name/ Stedsnavn	County/ Län	Locality/ Lokalitet	No. birds/ Antall liryper
1	Järpen	Jämtland	63°20'N 13°13'E	10
2	Vilhelmina	Västerbotten	64°30'N 16°40'E	2
3	Glen	Jämtland	62°60'N 13°10'E	10
4	Gäddede	Jämtland	64°30'N 14°10'E	10
5	Arjeplog	Norrbotten	66°20'N 16°10'E	6
6	Stora Sjöfallet	Norrbotten	67°30'N 18°40'E	3

Table 3. Sampling localities of Canada (1-9) and number of willow ptarmigan collected at each locality. - Lokaliteter for innsamling av lirype i Canada (1-9) og antall ryper samlet inn fra hver lokalitet.

Locality no./ Lokalitets nr.	Name/ Stedsnavn	Province/ Provins	Locality/ Lokalitet	No. birds/ Antall liryper
1	Chilkat Pass	British Columbia	59°50'N 136°40'W	29
2	Buchans	Newfoundland	48°30'N 57°30'W	2
3	Yellowknife	Northwest Territories	62°30'N 114°20'W	10
4	Richardson River	Northwest Territories	67°50'N 115°35'W	10
5	Baker Lake	Northwest Territories	64°15'N 96°10'W	5
6	Chick Lake	Northwest Territories	65°50'N 128°05'W	8
7	Tombstone, Depster	Yukon	64°30'N 138°20'W	2
8	Whitehorse	Yukon	60°20'N 135°15'W	5
9	Old Crow	Yukon	69°00'N 139°50'W	4

locality; the result was $\geq$ 5 from five localities, 4 from one locality and 2 from two localities. It must be remembered that the distances between localities here are much larger than for Scandinavia, and a huge area has been covered.

Russia

In co-operation with the "International Environmental Expedition 1994-1995", which carried the "Environmental message" from the Winter Olympic Games in Lillehammer to Nagano in Japan, willow ptarmigan were collected from two places in eastern

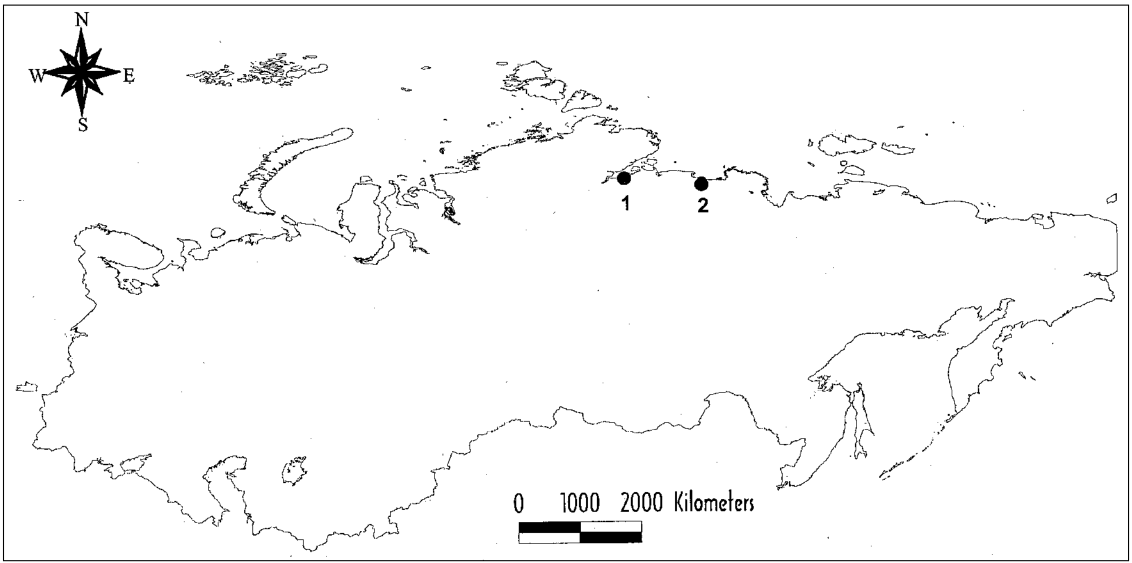

***Figure 4.** Map with localities in Russia. Numbers in map correspond with numbers in **table 4**. - Kart som viser innsamlingslokaliteter i Russland. Tallene på kartet korresponderer med tall i **tabell 4**.*

Siberia in late-winter 1995 (**Figure 4, Table 4**). These two localities are quite close and will not reveal differences within the country.

2.2 Field procedures

Birds from Chilkat Pass in Canada were shot with a shotgun (lead shots) or rifle, whereas all the birds from Sweden and Russia were shot with a shotgun (lead shots). Birds from Norway were mainly shot with a shotgun using steel shots, but lead shots were used for some (Kålås & Lierhagen 1992). Birds from Chilkat Pass in Canada, Gäddede in Sweden and all the localities in Norway were frozen (-20° C) as soon as possible after being shot. These birds were dissected in the laboratory later. Samples from other localities in Canada and Sweden, and both localities in Russia were removed immediately after the birds were shot. The birds were dissected with a sterile scalpel blade, using one blade per bird, and the liver and both kidneys were put in separate plastic containers and frozen (-20° C) as soon as possible. These samples were kept frozen until the tissues used for analysis were removed.

2.3 Laboratory procedures

All the liver and kidney samples from localities in Norway and from Chilkat Pass and Gäddede were removed after the birds had been thawed to approximately 0° C. Approximately 1.5 g (wet weight) of liver and kidneys were taken for analysis from the Norwegian birds (Kålås & Lierhagen 1992), and approximately 2.0 g (wet weight) from the birds from Chilkat Pass and all the localities in Sweden and Russia. From the other localities in Canada, 0.5-1.0 g (wet weight) was taken from kidneys and 1.0-1.5 g (wet weight) from livers. The samples were extracted with titanium steel knives and tweezers, and the tools were cleaned in 1 mol HNO_3 and rinsed in distilled water between each individual tissue sample.

2.4 Analytical methods

The kidney and liver samples were dried for about 17 hrs in a Christ LDC-1 freeze dryer. The final pressure and theoretical temperature for the freeze drying were 0.04 mbar and -50° C, respectively. In liver and kidneys from Chilkat Pass and Sweden, the dry weights as percentages of the wet weights were 30.3% (SD=2.5, n=67) and 27.8% (SD=2.6, n=70), respectively. In all the Norwegian material, the dry weights as percentages of the wet weights in liver and kidneys were 31.5% (SD=2.9, n=273) (Kålås & Lierhagen 1992) and 24.7% (SD=1.5, n=55), respectively.

Each sample (standard 0.4-0.6 g dry wt) was digested in 4.5 ml Scan pure concentrated (14.4 M) nitric acid (HNO_3) in a microwave oven (Milestone MLS 1200) in perfluoralcohoxil (PFA) containers. The elements were determined by atomic absorption spectroscopy (AAS) (Perkin Elmer, Model 1100B). A graphite furnace (HGA 700) with an automatic sampler (AS 90) was used for Pb, and a hydride system (FIAS 200) with an automatic sampler (AS 90) for Hg. The other elements (Cd, Cu, and Zn) were analysed by flame AAS.

The accuracy of the analytical procedures was checked against the National Bureau of Standards (NBS). The material from Norway was checked against bovine liver and dogfish liver DOLT-1 (Kålås & Lierhagen 1992), and that from Canada, Russia and Sweden against bovine liver 1577B (Cd, Cu, Hg, Pb and Zn) and dogfish liver DOLT-2 (Cd, Cu,

***Table 4**. Sampling localities of Russia (1-2) and number of willow ptarmigan collected at each locality. - Lokaliteter for innsamling av lirype i Russland (1-2) og antall ryper samlet inn fra hver lokalitet.*

Locality no./ Lokalitets nr.	Name/ Stedsnavn	Locality/ Lokalitet	No. birds/ Antall liryper
1	Sendasko	73°16′N 108°15′E	6
2	Noboridnova	72°59′N 119°59′E	5

Hg, Pb and Zn). The accuracy of the analytical procedures seems satisfactory for most of the metals (**Table 5**). There was no consistency in the variation in detectability within metals from one test to another. However, our results on all metals except Hg seem to be somewhat lower than the standards in DOLT-1 (**Table 5**). The analytical procedure gave the following standard detection limits (all values given as mg/kg^{-1} dry weight, the numbers in brackets show values used in the statistical analyses when the samples had a concentration below the detection limits): Norwegian material: Cd=0.01, Cu=0.5, Hg=0.015 (0.01), Pb=0.15 (0.1) and Zn=0.5, material from Canada, Russia and Sweden: Cd=0.01, Cu=0.5, Hg=0.01 (0.005), Pb=0.15 (0.1) and Zn=0.5. Except for Pb from Canada, few samples had values below the detection limit (Norwegian material: Hg: 3.0% (n=157), Pb: 3.0% (n=145), Canadian material: Hg: 0.6% (n=150), Pb: 20.7% (n=150), Russian material; Hg: 0% (n=22), Pb: 9.0% (n=22) and Swedish material: Hg 6.3% (n=79), Pb: 0% (n=79)). Detailed information about the metal content in individual birds is given in **Appendix 1**.

Table 5*. International reference standards analysed (National Bureau of Standards). All values given as mg kg^{-1} (dry weight). $\bar{x}$- mean, s.d.-standard deviation. From Kålås & Lierhagen (1992). - Analyserte referansestandarder for kontroll av analysekvalitet. Alle verdier gitt som mg kg^{-1} (tv). $\bar{x}$-gjennomsnitt, s.d.-standardavvik. Fra Kålås & Lierhagen (1992).*

Standard/Element	Certified value Sertifisert verdi $\bar{x}$	Present work Denne studien $\bar{x}$	s.d	n	NINA/Cert. % NINA/Sert. %
Bovine liver (1577A)					
Cadmium (Cd)	0.44	0.45	0.11	25	102
Copper (Cu)	158	162	15.4	61	103
Lead (Pb)	0.14	0.14	0.06	43	100
Mercury (Hg)	0.004	0.004	0.002	5	100
Zinc (Zn)	123	133	10.3	61	108
Bovine liver (1577B)					
Cadmium (Cd)	0.5	0.5	0.03	10	100
Copper (Cu)	160	178	3	10	111
Lead (Pb)	0.13	0.11	0.03	8	81
Mercury (Hg)	0.003	0.004	0.001	6	124
Zinc (Zn)	127	131	5.7	10	103
Dogfish-liver (DOLT-1)					
Cadmium (Cd)	4.18	3.99	0.23	7	95
Copper (Cu)	20.8	18	1.49	7	87
Lead (Pb)	1.36	1.12	0.22	7	82
Mercury (Hg)	0.225	0.236	0.019	7	105
Zinc (Zn)	92.5	82	4.4	6	87
Dogfish-liver (DOLT-2)					
Cadmium (Cd)	20.8	23.6	0.5	13	113
Copper (Cu)	25.8	31.5	0.7	13	122
Lead (Pb)	0.22	0.18	0.01	13	82
Mercury (Hg)	1.99	1.91	0.2	13	96
Zinc (Zn)	85.8	104	4.1	13	121

Not all birds were analysed for all elements in both liver and kidneys. Hence, the sample size for individual elements within areas may change between tissues. Some birds were shot using lead shots, giving a potential for Pb contamination. Although only tissues without any visible Pb contamination were analysed, some samples were discarded due to contamination. Samples with Pb levels above 10 mg/kg^{-1} (3% of the Norwegian material (Kålås & Lierhagen 1992), 7.3% of the Canadian material and 15.2% of the Swedish material) were not included.

2.5 Statistical methods

Because of a great variation in metal content within localities and the varying numbers of ptarmigan from different localities (29 to 2), we have chosen to use non-parametric statistics. Kruskal-Wallis tests are used to examine differences in metal content among localities within countries when more than two groups are compared (**Tables 6 and 7**).

The metal content in willow ptarmigan liver and kidneys from different localities are presented as medians with 1st and 3rd quartiles (**Figures 5 and 6**). To reveal any differences within Canada we have divided the localities into western Canada (Yukon and British Columbia) and central Canada (Northwest Territories). Data from eastern Canada (Newfoundland) have not been used in this comparison because of a low sample size. For this regional comparison, we have used the Mann-Whitney U-test corrected for continuity (**Tables 8 and 9**). To test for a correlation between Cd, Zn and Cu, the data have been analysed using linear correlation (**Table 10**). All the statistical tests are two-tailed and differences are considered significant when p values are <0.05.

All the tests and graphs are presented using Ky-plot, Version 2.0 beta 6. In **Figures 5 and 6**, the individual bars represent localities starting from the west in British Columbia in Canada and moving eastwards to Siberia in Russia. In these figures, the localities in Norway and Sweden are presented as Scandinavia, starting to the left with the south-westernmost locality and moving north-eastwards.

***Table 6**. Median metal content with interquartile range (Q_3-Q_1) in willow ptarmigan liver in each country given as mg kg^{1} dry weight. The first column gives the total number of ptarmigan analysed for each metal within each country (n). Kruskal-Wallis tests are used to display differences between localities within countries. df - degree of freedom, p - the exact probability and χ^2 - chi square value, and p – the exact pobability. – Metallinnhold angitt som median verdi mg kg^{1} tørrvekt i lever fra lirype (Q_3-Q_1 – interkvartil spredning). Den første kolonnen viser totalt antall liryper analysert for hvert enkelt land og metall (n). Kruskal-Wallis test er brukt for å påvise forskjeller mellom lokaliteter innen land. df – antall frihetsgrader, χ^2 - chi square verdi, p – eksakt sannsynlighet.*

	n	Median	Q_3-Q_1	df	χ^2	p
Cadmium (Cd)						
Canada	75	21.67	20.16	8	37.97	<0.001
Norway	87	6.7	7.05	14	43.74	<0.001
Sweden	38	8.7	4.45	5	9.88	0.08
Russia	11	6.03	3.56	1	0.03	0.86
Lead (Pb)						
Canada	71	0.114	0.156	8	26.16	<0.001
Norway	84	0.84	1.51	14	45.68	<0.001
Sweden	33	0.529	0.616	5	7.56	0.18
Russia	11	0.179	0.264	1	1.64	0.20
Mercury (Hg)						
Canada	75	0.050	0.044	8	45.85	<0.001
Norway	87	0.032	0.027	14	40.29	<0.001
Sweden	38	0.018	0.031	5	23.74	<0.001
Russia	11	0.033	0.02	1	6.53	0.01
Copper (Cu)						
Canada	75	15.44	4.46	8	28.48	<0.001
Norway	87	12.3	2.7	14	26.32	0.02
Sweden	38	13.23	2.8	5	4.85	0.43
Russia	11	15.29	4.03	1	0.3	0.58
Zinc (Zn)						
Canada	75	105.89	18.04	8	21.97	0.004
Norway	87	86	23.5	14	30.25	0.007
Sweden	38	88.18	20.02	5	4.47	0.48
Russia	11	87.18	20.36	1	0.83	0.36

***Table 7**. Median metal content with interquartile range(Q_3-Q_1) in willow ptarmigan kidney in each country given as mg kg^{1} dry weight. The first column gives the total number of ptarmigan analysed for each metal within each country (n). Kruskal-Wallis tests are used to display differences between localities within countries. df - degree of freedom, χ^2 - chi square value, and p - the exact probability. - Metallinnhold angitt som median verdi mg kg^{1} tørrvekt i nyre fra lirype (Q_3-Q_1 – interkvartil spredning). Den første kolonnen viser totalt antall liryper analysert for hvert enkelt land og metall (n). Kruskal-Wallis test er brukt for å påvise forskjeller mellom lokaliteter innen land. df – antall frihetsgrader, χ^2 - chi square verdi, p – eksakt sannsynlighet.*

	n	Median	Q_3-Q_1	df	χ^2	p
Cadmium (Cd)						
Canada	75	120.75	108.49	8	37.23	<0.001
Norway	70	74.31	87.24	13	45.52	<0.001
Sweden	41	67.13	46.94	5	13.91	0.02
Russia	11	49.53	38	1	0.3	0.58
Lead (Pb)						
Canada	68	0.326	0.569	8	19.84	0.01
Norway	58	0.82	1.498	13	46.26	<0.001
Sweden	34	0.694	0.356	5	10.79	0.05
Russia	11	0.556	0.214	1	0.03	0.85
Mercury (Hg)						
Canada	75	0.146	0.114	8	40.46	<0.001
Norway	70	0.111	0.086	13	48.40	<0.001
Sweden	41	0.084	0.05	5	7.08	0.22
Russia	11	0.068	0.037	1	4.8	0.03
Copper (Cu)						
Canada	75	20.91	7.72	8	23.45	0.003
Norway	70	14.7	5.08	13	35.27	<0.001
Sweden	41	15.91	3.02	5	14.67	0.01
Russia	11	19.01	5.57	1	0.83	0.36
Zinc (Zn)						
Canada	75	156.23	35.28	8	21.05	0.007
Norway	70	129.5	38	13	31.07	0.003
Sweden	41	126.78	24.84	5	13.44	0.02
Russia	11	155.93	22.62	1	0.13	0.72

***Table 8**. Comparison of metal content in liver of willow ptarmigan from mid-Canada (Northwest Territories) and western Canada (Yukon and British Columbia). All Mann-Whitney tests are two-tailed and corrected for continuity. Means, variance and median values are given as mg kg^{-1} dry weight. Statistical significance given as: N.S. P>0.05 (not significant); *, P ≤0.05; **, P ≤0.01; ***, P≤ 0.001. – Sammenligning av metallinnhold i lever fra liryper fra midt-Canada (Northwest Territories) og vest-Canada (Yukon og British Columbia). Alle Mann-Whitney testene er to-halet og korrigert for kontinuitet. Gjennomsnitt, varians og median verdier er gitt som mg kg^{-1} tørr vekt. Statistisk sikkerhet er gitt som: N.S. P>0.05 (ikke signifikant); *, P ≤0.05; **, P ≤0.01; ***, P≤ 0.001.*

	Mid-Canada	Western Canada	Statistic	P
Cadmium (Cd)				
N	33	40		
Mean	17.72	33.42	T=4.594	***
Var	151.67	329.26		
Median	12.88	29.44		
Lead (Pb)				
N	33	36		
Mean	0.184	0.491	T=2.823	**
Var	0.063	1.980		
Median	0.100	0.166		
Mercury (Hg)				
n	33	40		
Mean	0.106	0.040	T=6.069	***
Var	0.005	0.000		
Median	0.080	0.037		
Copper (Cu)				
n	33	40		
Mean	17.52	17.79	T=3.530	***
Var	12.73	445.00		
Median	16.80	13.93		
Zinc (Zn)				
n	33	40		
Mean	112.75	111.74	T=0.017	N.S.
Var	513.95	465.65		
Median	105.67	106.78		

***Table 9**. Comparison of metal content in kidneys of willow ptarmigan from mid-Canada (Northwest Territories) and western Canada (Yukon and British Columbia). All Mann-Whitney tests are two-tailed and corrected for continuity. Means, variance and median values are given as mg kg^{-1} dry weight. Statistical significance given as: N.S. P>0.05 (not significant); *, P ≤0.05; **, P ≤0.01; ***, P≤ 0.001. – Sammenligning av metallinnhold i nyre fra liryper fra midt-Canada (Northwest Territories) og vest-Canada (Yukon og British Columbia). Alle Mann-Whitney testene er to-halet og korrigert for kontinuitet. Gjennomsnitt, varians og median verdier er gitt som mg kg^{-1} tørr vekt. Statistisk sikkerhet er gitt som: N.S. P>0.05 (ikke signifikant); *, P ≤0.05; **, P ≤0.01; ***, P≤ 0.001.*

	Mid-Canada	Western Canada	Statistic	P
Cadmium (Cd)				
n	33	40		
Mean	116.87	206.25	T=2.876	**
Var	7873.48	31294.94		
Median	92.65	138.90		
Lead (Pb)				
n	32	35		
Mean	0.895	0.868	T=3.100	**
Var	3.932	0.959		
Median	0.211	0.538		
Mercury (Hg)				
n	33	40		
Mean	0.358	0.128	T=4.924	***
Var	0.130	0.003		
Median	0.110	0.208		
Copper (Cu)				
n	33	40		
Mean	20.95	25.00	T=1.829	N.S.
Var	27.68	117.81		
Median	19.41	22.26		
Zinc (Zn)				
n	33	40		
Mean	160.93	168.50	T=1.491	N.S.
Var	1476.87	2145.67		
Median	149.98	161.95		

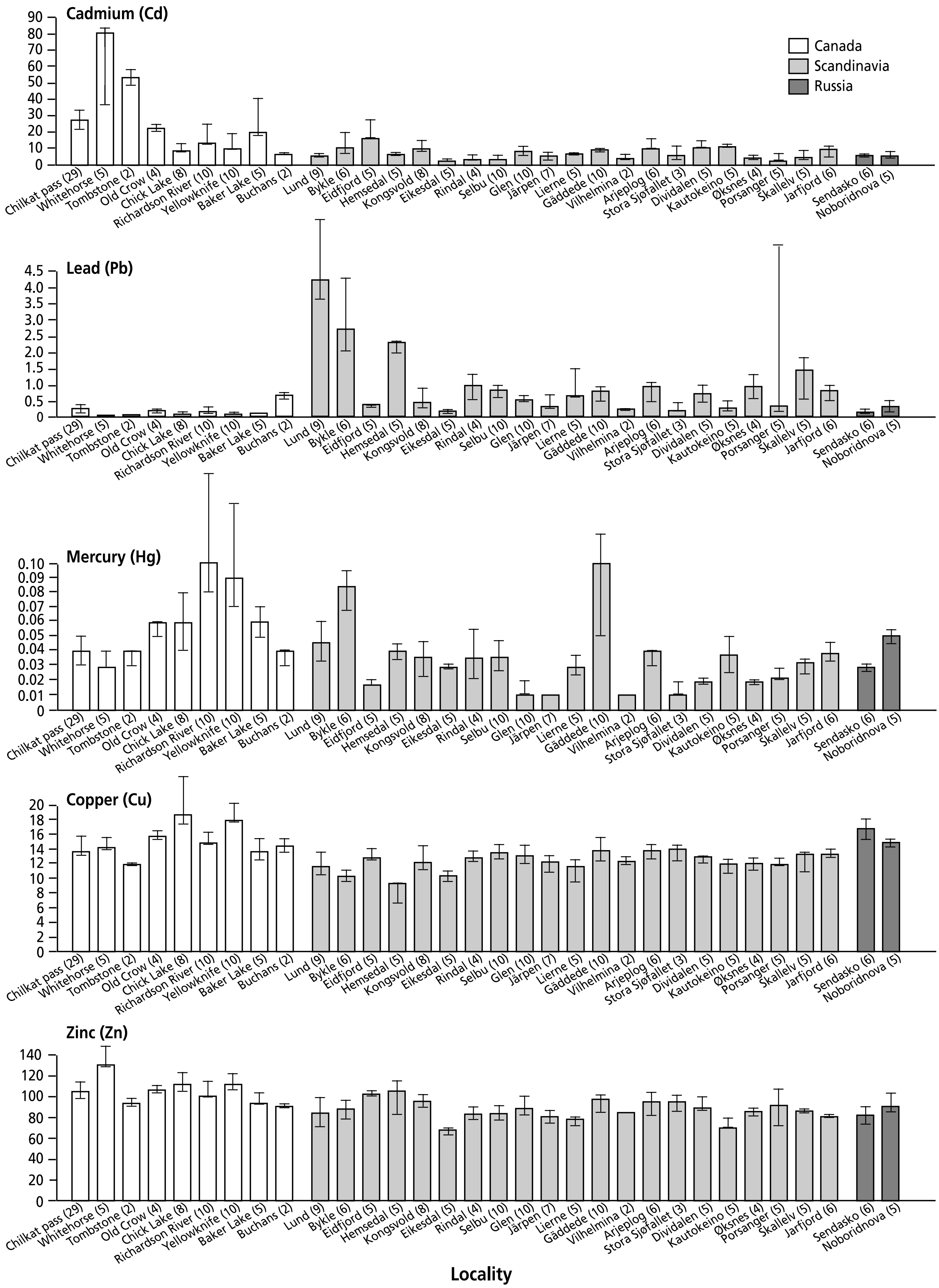

Figure 5. *The distribution of heavy metals in willow ptarmigan liver is shown by locality, in Canada, Scandinavia and Russia. Localities are shown from west to east for Canada and Russia and from south to north in Scandinavia. The bars show the median value, and the error bars show 1st and 3rd quartile. Metal content is given as mg kg^{-1} dry weight. – Fordelingen av tungmetaller i lever fra lirype er vist for hver enkelt lokalitet i Canada, Skandinavia og Russland. Lokalitetene er vist fra vest mot øst for Canada og Russland og fra sør mot nord for Skandinavia. Søylene viser median verdier og 1. og 3. kvartil. Metallinnholdet er gitt som mg kg^{-1} tørr vekt.*

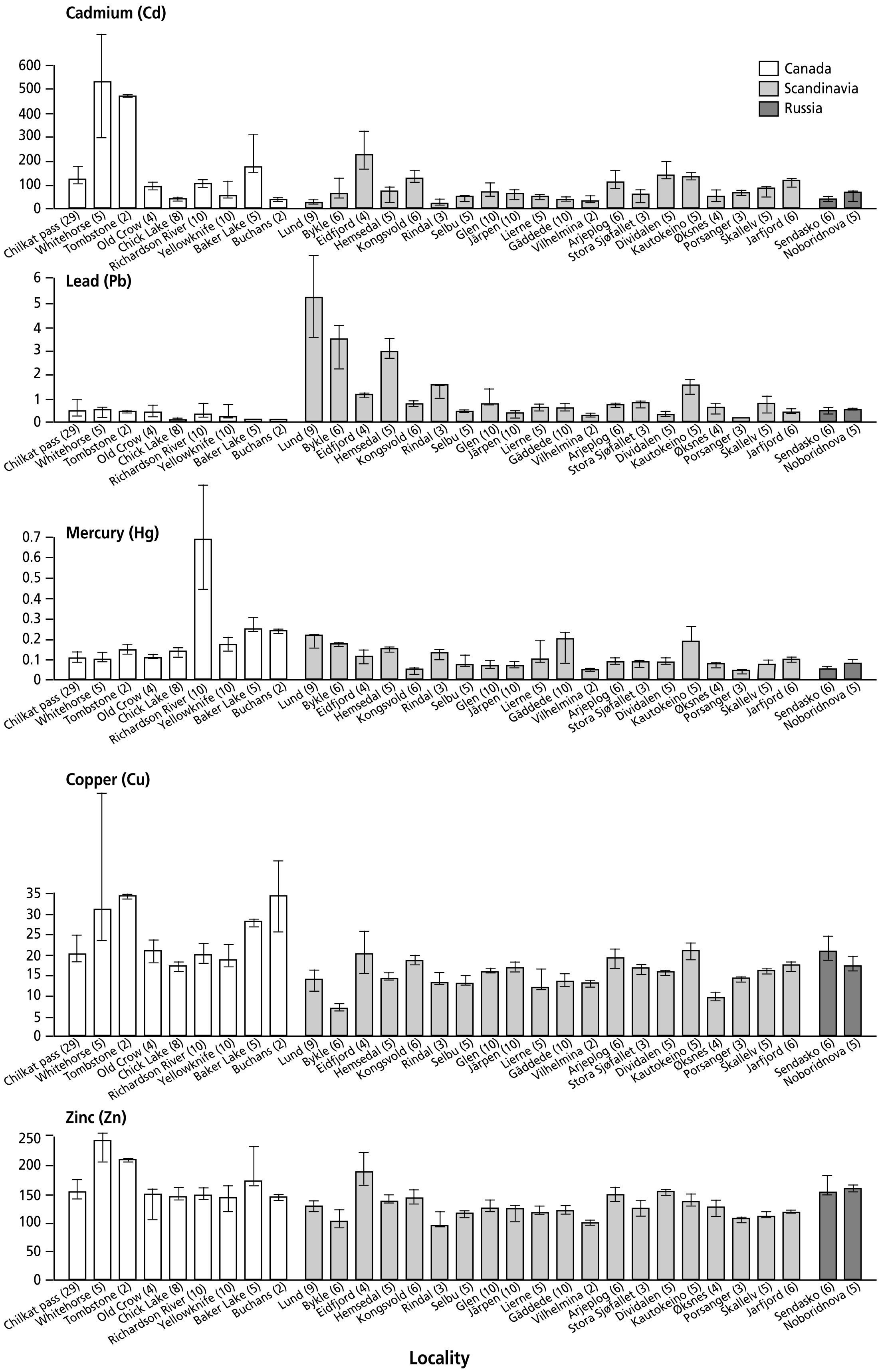

Figure 6. *Shows the distribution of heavy metals in willow ptarmigan kidneys by locality, in Canada, Scandinavia and Russia. Localities are shown from west to east for Canada and Russia and from south to north in Scandinavia. The bars show the median value, and the error bars show 1st and 3rd quartile. Metal content is given as mg kg^{-1} dry weight. – Fordelingen av tungmetaller i nyre fra lirype er vist for hver enkelt lokalitet i Canada, Skandinavia og Russland. Lokalitetene er vist fra vest mot øst for Canada og Russland og fra sør mot nord for Skandinavia. Søylene viser median verdier og 1. og 3. kvartil. Metallinnholdet er gitt som mg kg^{-1} tørr vekt.*

***Table 10**. Linear corrrelation between cadmium (Cd), zinc (Zn) and copper (Cu) in liver and kidney. df-degrees of freedom, r-correlation coefficient , and significance level; ***, P ≤0.001. - Lineær korrrelasjon mellom kadmium (Cd), sink (Zn) og kobber (Cu) i lever og nyre. df-antall frihetsgrader, r-korrelasjons koeffisient og statistisk sikkerhet; ***, P ≤0.001.*

	df	r	P
Liver			
Cd/Zn	208	0.55	***
Cd/Cu	208	0.25	***
Cu/Zn	208	0.54	***
Kidney			
Cd/Zn	195	0.74	***
Cd/Cu	195	0.72	***
Cu/Zn	195	0.67	***

3 Results and discussion

3.1 Cadmium (Cd)

Cadmium is a relatively rare element, which most often naturally occur together with zinc. It is a non-essential element with no known positive biological effect. Accumulation of Cd varies a lot among different plant species and vertebrates. Concentrations may vary in different organs and cadmium accumulates with age (Flick et al. 1971, NRCC 1979). Earlier studies in Norway have focused on Cd contamination of game species as a result of long-range atmospheric pollution (Frøslie et al. 1986, Fimreite et al. 1990). However, the regional pattern shown in the present study and in the study by Kålås & Lierhagen (1992) does not agree with other information about long-range Cd contamination in Norway (e.g. Steinnes et al. 1989).

Although earlier studies have shown that elevated levels of cadmium in captive birds and mammals may produce several sublethal effects, no negative effects have so far been reported in free-living game species (but see Pedersen & Sæther 1998). Eisler (1985) suggested that higher Cd values than 10 mg/kg^{-1} wet weight (approximately 30-40 mg/kg^{-1} dry weight) in liver and kidneys in vertebrates indicate possible Cd contamination. Using this limit, game species such as tetraonids and cervides are contaminated with cadmium at several localities throughout their ranges.

There is a considerable variation in the Cd content in kidneys and liver of willow ptarmigan among localities in both Canada and Scandinavia (**Figures 5 and 6, Tables 6 and 7**). The highest median value from one locality is found in Canada, both in liver and kidneys. In accordance with earlier studies (e.g. Pedersen & Myklebust 1993), 6-10 times more Cd is accumulated in kidneys than in liver at all the localities. Compared with other species, willow ptarmigan seem to have a high kidney:liver ratio; other species normally have about two to three times more Cd in their kidneys than in their liver (Scheuhammer & Tempelton 1990).

In Norway, regional differences in the Cd content of willow ptarmigan livers have been reported earlier (Kålås & Lierhagen 1992). The results of the present study show the same general pattern also for kidneys from the same birds, namely that the Cd content is at its highest in the central mountain areas of southern Norway and inland localities in the counties of Troms and Finnmark (**Figures 5 and 6, Appendices 2 and 3**).

Earlier studies have shown high levels of Cd in willow ptarmigan from southern parts of Norway (mean concentration in livers of adult willow ptarmigan approximately 10 mg/kg^{-1} dry weight (Herredsvela & Munkejord 1988, Fimreite et al. 1990)). However, Kålås & Lierhagen (1992) reported several inland localities in central and northern Norway with even higher Cd levels in liver samples (five localities with a mean above 20 mg/kg^{-1}), and 33% (n=273) of the analysed liver samples had more than 10 mg/kg^{-1}. The same general pattern is also found in kidneys, earlier studies suggesting the existence of Cd contamination in willow ptarmigan in southern parts of Norway (mean concentration in kidneys of adult willow ptarmigan was approximately 70 mg/kg^{-1} dry weight (Herredsvela & Munkejord 1988, Fimreite et al. 1990)). In the present study, results from five localities in central and northern Norway show mean Cd levels in kidneys above 100 mg/kg^{-1}, and 53% (n=70) of the analysed kidney samples contained more than 70 mg/kg^{-1}.

The discrepancy between the findings in willow ptarmigan and other organisms can be explained as follows. The various plants which willow ptarmigan feed on differ greatly in their Cd content (Myklebust et al. 1993); the willow (*Salix* spp.) contains most (Myklebust 1992), more than 100 times more than is found in, for example, bilberry (*Vaccinium myrtillus*), another important food plant. Willow is a preferred food plant, and is eaten as long as it is available during autumn, winter and spring (Norris et al. 1979). Hence, the Cd content, especially in the liver which mostly reflects the immediate Cd exposure of the bird, depends very much on the extent to which willow is eaten (Myklebust 1992). This and the quantity actually eaten vary from area to area and season to season, partly depending on the snow cover, and this will mask the possible accumulation of Cd caused by long-range pollution. Long-range atmospheric Cd contamination of southern parts of Norway is probably causing an elevated Cd level in species like willow ptarmigan. However, due to «natural» pollution of Cd through intake of willow in more northerly areas, direct comparison of the Cd level in willow ptarmigan from different localities cannot reveal such a relationship. It is, however, possible to use this data set to evaluate possible future regional changes in the Cd level in willow ptarmigan. When performing such an evaluation, it is important to remember to collect birds of the same age at the same time of year as used here.

The Cd content in central Canada (Northwest Territories) is comparable with that in Scandinavia and Russia (eastern Siberia), at least for kidneys and to some degree for liver. However, in both tissues the median for the whole of Canada is considerably higher than for the other countries (**Tables 6 and 7**). Furthermore, birds from the localities in western Canada (British Columbia and Yukon) contain significantly more Cd than those in central Canada (Northwest Territories) (**Tables 8 and 9**). Although the distinction, here, is made between western and central Canada, it is evident that two localities, Whitehorse and Tombstone, bring about the significant difference between the two regions.

If we use the criteria proposed by Eisler (1985) as an indication of Cd contamination (Cd values > 10 mg/kg^{-1} wet weight (approximately 30 mg/kg^{-1} dry weight in liver and 40 mg/kg^{-1} dry weight in kidneys)), we find that 32% (n=75) of the analysed liver samples contained more than 30 mg/kg^{-1} and 92% (n=75) of the analysed kidney samples contained more than 40 mg/kg^{-1}. Furthermore, the Cd level in birds collected at localities 7 and 8 was exceptionally high, several birds having > 50 mg/kg^{-1} in their liver and > 400 mg/kg^{-1} in their kidneys (**Figure 3, Appendix 1**). However, it is difficult to ascribe these high Cd levels to anything other than «natural» Cd contamination, possibly through a high intake of willow. A recent review by Jensen et al. (1997) interestingly showed that caribou (*Rangifer tarandus*) from herds living in the same area as our locality 8 also had significantly more Cd in their kidneys than other herds in the Yukon and Northwest Territories. The authors suggested that these differences may have been caused by a higher intake of willow in some herds, and this is in line with our findings in willow ptarmigan.

The relatively large variation at one and the same locality makes it more difficult to evaluate regional differences in the data from Sweden (**Tables 6 and 7**). Most localities have the same Cd level as the more moderately contaminated ones in Norway, but localities 3 and 5 have relatively high levels (**Figure 2, Appendices 2 and 3**). Earlier studies from three localities in central and northern Sweden have shown low to moderate levels of Cd in willow ptarmigan (mean concentration in kidneys approximately 30-40 mg/kg^{-1} dry weight (Mörner & Brittas 1994)). The present study has not revealed any liver samples with more than 30 mg/kg^{-1}, but 32% (n=38) had a Cd content above 10 mg/kg^{-1}. As many as 93% (n=41) of the analysed kidney samples had a Cd content above 40 mg/kg^{-1} (**Appendix 1**). This indicates a higher proportion of Cd-contaminated willow ptarmigan in the present study compared to the findings of Mörner & Brittas (1994). However, as already mentioned for the localities on the Norwegian side of the border, these high Cd levels may be due to «natural» Cd contamination through a high intake of willow.

The data from the two localities in Russia show Cd levels comparable to the more moderately contaminated ones in Canada, Norway and Sweden (**Appendices 2 and 3**). As no data are available from earlier Russian studies, and as both localities are in eastern Siberia, nothing can be said about any regional differences in the Cd level. Only 18% (n=11) of the liver samples held more than 10 mg/kg^{-1} Cd, whereas 64% (n=11) of the analysed kidney samples had more than 40 mg/kg^{-1} (**Appendix 1**). Again, willow intake probably explains the relatively high Cd level in kidneys.

Cd accumulation in tissue seems to be largely bound to low-molecular, sulphohydroxyl-rich proteins, so-called metallothioneins (MT) (Cherian & Goyer 1978). All types of tissue can probably synthesise MT, but the capacity seems to vary from tissue to tissue. It has, furthermore, been shown that MT are also capable of binding several other metals (Zn, Cu, Hg) and are probably important for detoxifying and storing several toxic metals.

A study of the Cd/MT relationship in willow ptarmigan from Norway revealed that birds from naturally Cd-contaminated areas contained more MT than those from areas with a low natural Cd level (Pedersen & Hylland 1995). This shows that MT in willow ptarmigan may be an important mechanism for detoxifying Cd, and that a population which experiences high loads, for instance through a high intake of willow, may «reply» by increasing their MT production.

3.2 Lead (Pb)

Lead is a relatively common, non-essential metal. Although it is found naturally in soil, it is only absorbed to a minor extent by plants. Hence, most of the Pb found in plants is caused by atmospheric deposition (Berthelsen et al. 1995). Pb mainly accumulates in tissues like kidneys, liver and bone in vertebrates, but is also found to a minor extent in muscle and brain tissues (Nybø 1991, Kålås & Fjølstad 1995). Pb is one of the most toxic metals for animals, and as it can cross both the blood-brain and placenta barriers, it affects the nervous system and the production of haemoglobin (Goyer 1986, Eisler 1988a, Nybø 1991). This makes the metal potent for causing chronically sub-lethal effects as well as being lethal.

In Scandinavia, Pb shows a typical pattern of being deposited through long-range atmospheric transport of heavy metals from Europe (Steinnes 1987, Steinnes et al. 1989), the highest deposition being in southern and coastal parts of Scandinavia and decreasing deposition northwards. This is evident from surveys of moss (*Hylocomium splendens*) carried out in Norway from 1977 to 1995 (Berg & Steinnes 1997). This pattern is also found in small and large herbivores (Frøslie et al. 1984, Frøslie et al. 1985, Kålås & Lierhagen 1992, Kålås et al. 2000).

The moss surveys also show a great reduction of the Pb level in Norway during the last two decades (Berg & Steinnes 1997). From 1977 to 1990 there was a decrease of 50-70% for most metals, and a further 30% decrease for Pb between 1990 and 1995. This is probably mostly because of the removal of lead as an anti-knocking agent in petrol.

The localities in Norway and Canada show a significant variation in Pb concentration in kidneys and liver of willow ptarmigan (**Figures 5 and 6, Tables 6 and 7**), but no significant difference was found between localities within Sweden and Russia. The levels in Sweden and Russia are comparable to those in Canada and to low-level localities in Norway, although the two localities in Russia seem to record less Pb, especially in liver samples. In accordance with earlier studies (Kålås & Fjølstad 1995), little difference was found in the Pb accumulation in kidneys and liver, although the former often have somewhat more Pb (**Tables 6 and 7, Appendices 1, 2 and 3**).

The highest median value for all localities within one country is found in Norway, both in liver and kidneys, by far the highest being in southern Norway (**Figures 5 and 6, Tables 6 and 7**) (see also Kålås et al. 2000). This indicates that the cause in willow ptarmigan, too, is long-range transport of Pb. Compared with Canada, three localities (loc. 1, 2, 4), have extremely high levels. Significantly more Pb is recorded in the western than central localities in Canada (**Tables 8 and 9**). Whether this reflects a higher contamination level on the west coast through long-range atmospheric transport of heavy metals from more densely populated areas in British Columbia and western USA is not known.

3.4 Mercury (Hg)

In common with cadmium and lead, mercury is a non-essential element. It is the most acutely toxic metal dealt with in this report, and is capable of concentrating at higher levels in the food web. Hg exists naturally in very low concentrations in soil and like Pb is poorly absorbed by plants. It is therefore not considered to pose a great danger for herbivores (Lindqvist 1991, Kålås & Lierhagen 1992). Hg accumulates in the liver, kidneys and brain of vertebrates. In the kidneys, it will mostly be bound to metallothioneins (MT). Hg can cross the blood-brain and placenta barriers. It will affect the kidneys, CNS and gonads at high concentrations. It is also known to cause eggshell thinning. Hg is carcinogenic (Nybø 1991).

The Hg level in liver varies significantly from one locality to another in all the countries and in kidneys everywhere except Sweden (**Tables 6 and 7**). The level is somewhat higher in kidneys than liver (**Figures 5 and 6, Tables 6 and 7, Appendices 1, 2 and 3**). Unlike Pb, Hg shows no distinct regional pattern in Scandinavia, but a few localities have higher levels than average. In Sweden, it is especially Gäddede (loc. 4), and in Norway Bykle (loc. 2) that have high concentrations in liver (**Figure 5**).

In Canada, significantly more Hg is recorded in both tissues in central than in western localities (**Tables 7 and 8**). This is the localities opposite of the pattern found in Cd and Pb. Several localities record relatively high quantities of Hg in liver, but only one, Richardson River (**Figure 3**, loc. 4), stands out with an extremely high concentration in kidneys (**Figure 6, Appendix 3**). This is difficult to explain just by natural variation and nearby silver mines could have some effect.

3.5 Copper (Cu) and Zinc (Zn)

Copper and zinc are both essential metals and are necessary for the functions of many enzymes. Homeostatic regulations are well developed and control the concentrations in animals. However, these two metals compete with Cd in absorption from the diet. This seems to be caused largely by the competition for metallothioneins in the mucosa (Nybø 1991). Although these three elements compete during absorption they are usually intercorrelated (Nybø 1991, Pedersen & Myklebust 1993), as also found in the present study (**Table 10**).

Since Cu and Zn are essential metals, and their intake and excretion are regulated, they show much less variation between and within localities than the non-essential elements (**Figures 5 and 6, Appendices 2 and 3**). Also in plants these metals show less variation both between and within different species (Berthelsen et al. 1995). Neither Cu nor Zn concentrations seem to be influenced by direct atmospheric deposition in plants (Berthelsen et al. 1995).

For both elements, significant variation was found in liver and kidneys among localities in Canada and Norway, whereas samples from Sweden only showed a significant variation in kidneys (**Tables 6 and 7**). The levels of Cu and Zn are higher in kidneys than liver. Comparison between western and central Canada shows only a significant difference for Cu in liver, the higher content being found in central Canada (**Tables 8 and 9**). There are no prominent regional differences either among or within countries, although some localities in Canada seem to have higher Cu concentrations in kidneys compared with Scandinavia and Russia (**Figure 6, Table 7, Appendix 3**). These are the same localities that have relatively high levels of Cd and Zn in kidneys. The variation found in Cu and Zn can perhaps be best explained as natural variation in soil minerals. However, we cannot exclude local or long-range transported deposition from mines or smelters.

4 Summary

The willow ptarmigan is one of the very few species that have a circumpolar distribution and live in the arctic-alpine environment throughout the year. As part of the «Arctic Monitoring and Assessment Programme (AMAP)», a circumpolar survey of heavy metals in liver and kidneys of willow ptarmigan was carried out from 1992 to 1995. A total of 75 birds were sampled from 9 localities in Canada, 87 from 15 localities in Norway, 11 from 2 localities in Russia and 41 from 6 localities in Sweden. The results of the analyses of cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg) and zinc (Zn) in these samples are presented here.

To allow comparison between areas, mainly adult birds shot during autumn and winter have been used. The elements were determined by atomic absorption spectroscopy (AAS) and the accuracy of the analytical procedures was checked against the National Bureau of Standards (NBS). Some of the birds were shot using lead shots, giving a potential for Pb contamination. Hence, samples with Pb levels above 10 mg/kg^{-1} were not included.

Cadmium (Cd). A considerable variation in the Cd content in kidneys and liver of willow ptarmigan was found among localities in both Canada and Scandinavia. The highest median value from one locality is found in Canada, both in liver and kidneys. As found in earlier studies, 6-10 times more Cd is accumulated in kidneys than in liver at all the localities. In Norway, the present study shows the same regional pattern in both liver and kidneys as was found in earlier studies, namely that the Cd content is highest in central mountain areas in southern Norway and inland localities in the northern counties of Troms and Finnmark.

High levels of Cd have been found earlier in willow ptarmigan from southern Norway. However, a more recent study revealed several inland localities in central and northern Norway with even higher Cd levels in liver samples (33% (n=273) of the analysed samples had a Cd content above 10 mg/kg^{-1}). The same general pattern is also found in kidneys. In the present study, 53% (n=70) of the analysed kidney samples had a Cd content above 70 mg/kg^{-1}.

Willow contains more than 100 times more Cd than, for instance, bilberry. Willow is a preferred food plant and is eaten as long as it is available during autumn, winter and spring. Hence, the Cd content, especially in the liver, very much depends on the amount of willow eaten. Since this willow intake may mask the possible accumulation of Cd from long-range pollution, direct comparison of the Cd level in willow ptarmigan from different localities cannot reveal the effects of long-range pollution. This can, however, be achieved by comparing relative changes over time, provided birds of the same age as here are collected at the same time of year.

The Cd content in central Canada (Northwest Territories) is comparable with Scandinavia and Russia (eastern Siberia), at least for kidneys. However, in both liver and kidneys, the median for the whole of Canada is considerably higher than for the other countries. A total of 32% (n=75) of the analysed liver samples had a Cd content above 30 mg/kg^{-1}, whereas 92%

(n=75) of the analysed kidney samples contained more than 40 mg/kg^{-1}. Furthermore, the Cd levels in birds collected in Tombstone and Whitehorse, Yukon, were exceptionally high, several having > 50 mg/kg^{-1} in liver and > 400 mg/kg^{-1} in kidneys. However, it is difficult to ascribe these high levels to anything other than «natural» Cd contamination, perhaps through a high willow intake.

It is difficult to evaluate regional differences in the data from Sweden, but most of the localities have the same Cd level as the moderately contaminated ones in Norway. Earlier studies in central and northern Sweden have shown low to moderate levels of Cd in willow ptarmigan (kidneys 30-40 mg/kg^{-1}). No liver samples had more Cd than 30 mg/kg^{-1}, but 32% (n=38) had more than 10 mg/kg^{-1}. However, 93% (n=41) of the kidney samples contained more than 40 mg/kg^{-1}. This indicates a higher proportion of Cd-contaminated willow ptarmigan in the present study compared to earlier studies. These high Cd levels may be due to «natural» Cd contamination through a high intake of willow.

The data from Russia show Cd levels comparable to fairly moderately Cd-contaminated localities in Canada, Norway and Sweden. Lack of data prevents the recognition of any regional differences in the Cd level. In the liver samples, 18% (n=11) contained more than 10 mg/kg^{-1} Cd, whereas 64% (n=11) of the kidney samples held more than 40 mg/kg^{-1}. Intake of willow probably explains the relatively high Cd level in kidneys.

Lead (Pb). A significant variation is found in the Pb concentration in kidneys and liver of willow ptarmigan among localities in Norway and Canada, but not so in Sweden and Russia. The levels in Sweden and Russia are comparable to those in Canada and to low-level localities in Norway. The highest median value from all localities within individual countries is found in Norway, both in liver and kidneys. The highest Pb content is found in the southern part of Norway, indicating an effect of long-range pollution in willow ptarmigan, too. In Canada, there is a significantly higher level in western than central Canada. Whether this reflects a higher contamination level on the west coast through long-range atmospheric transport of heavy metals from more densely populated areas in British Columbia and western USA is not known.

Mercury (Hg). The Hg level in liver shows significant variation among localities in all the countries, and in kidneys in all the countries except Sweden. In Scandinavia, there is no distinct regional pattern, as is found in Pb. Canada shows a significantly higher Hg level in central than in western regions in both tissues, which is the opposite from the patterns found in Cd and Pb.

Copper (Cu) and Zinc (Zn). For both elements, a significant variation was found in liver and kidneys among localities in Canada and Norway, but the variation was only significant in kidney samples from Sweden. Comparison between western and central Canada shows that there is only a significant difference for Cu in liver, the higher amount being found in central Canada. There are no prominent regional differences either among or within countries, although some localities in Canada seem to have more Cu concentrated in kidneys than is found in Scandinavia and Russia. These are the same localities that have relatively high levels of Cd and Zn in kidneys. The variations found in Cu and Zn may be best explained as natural variation in soil minerals. However, we cannot exclude local or long-range transported deposition from mines or smelters.

5 Sammendrag

Lirypa er en av svært få arter som har en sirkumpolar utbredelse og som lever i det arktisk-alpine økosystemet gjennom hele året. Som et delprosjekt under "Arctic Monitoring and Assessment Programme (AMAP)" ble det i 1992 til 1995 foretatt en sirkumpolar kartlegging av tungmetaller i lever og nyre fra lirype. Det ble analysert 75 liryper fra 9 forskjellige lokaliteter i Canada, 87 liryper fra 15 lokaliteter i Norger, 11 liryper fra 2 lokaliteter i Russland og 41 liryper fra 6 lokaliteter i Sverige. Her presenteres resultatene for kadmium (Cd), kobber (Cu), bly (Pb), kvikksølv (Hg) og sink (Zn) fra samtlige lokaliteter.

For å kunne sammenligne resultater fra forskjellige områder har vi hovedsakelig benyttet voksne ryper skutt om høsten eller vinteren. Til metallanalysene ble det brukt atom absorpsjon spectroskopi (AAS) og nøyaktigheten av analysene ble kontrollert i mot National Bureau of Standards (NBS). Enkelte av rypene ble skutt med blyhagl. På grunn av mulig kontaminering fra blyhagl ble prøver med Pb-verdier over 10 mg kg^{-1} ikke benyttet.

Kadmium (Cd). Det ble funnet relativt stor variasjon i Cd-innhold i lever og nyre fra ryper fra forskjellige lokaliteter både i Canada og Skandinavia. Den høyeste verdien fra en lokalitet ble funnet i Canada, både i lever og nyre. I tråd med hva som er funnet i tidligere undersøkelser ble det funnet 6-10 ganger mer Cd i nyrer enn i lever for alle lokaliteter.

For Norge viste denne undersøkelsen samme regionale mønster som funnet i en tidligere landsomfattende undersøkelse, både i lever og nyre; nemlig at Cd-innholdet er høyest i lokaliteter fra sentrale høyfjellsområder i Sør-Norge og fra innlandslokaliteter i Troms og Finnmark.

I vier er det mer enn 100 ganger høyere Cd-innhold enn f.eks i blåbær. Vier er en preferert næringsplante for lirype og spises så lenge den er tilgjengelig utover høsten før snølaget blir for tykt. Dette fører til at Cd-innholdet, spesielt i lever, er svært avhengig av hvor mye vier lirypa til enhver tid spiser. Hvor lenge og hvor mye lirypene spiser vier kan derfor kamuflere mulig Cd-akkumulering fra langtransportert forurensning. På grunn av "naturlig" forurensning av Cd gjennom inntak av vier vil ikke denne undersøkelsen, gjennom en direkte sammenligning av ryper fra forskjellige områder, kunne påvise langtransportert forurensning. Dette kan imidlertid gjøres gjennom å påvise relative endringer innen og mellom områder over tid. Ved en slik tilnærming er det viktig å samle inn ryper av samme alder og på samme årstid som de vi har benyttet her.

På 1980-tallet ble det funnet spesielt høye Cd-nivå i liryper fra sørvestlige områder i Norge. Imidlertid har nyere undersøkelser vist at mange innlandslokaliteter fra midt- og Nord-Norge, har ennå høyere Cd-nivå (33% (n=273) av analyserte lever-prøver har Cd-innhold over 10 mg kg^{-1}). Det samme generelle mønster finner vi i denne undersøkelsen i nyrer, hvor totalt 53% (n=70) av de analyserte nyre-prøvene har et Cd-innhold over 70 mg kg^{1}.

Cd-innholdet i liryper fra midt-Canada (Northwest Territories) er på samme nivå som i Skandinavia og Russland (øst-Sibir). Imidlertid er gjennomsnitts-nivået totalt sett for Canada vesentlig høyere, både i lever og nyre, sammenlignet med de andre landene. Totalt 32 % (n=75) av lever-prøvene fra Canada har et Cd-innhold over 30 mg kg^{-1}, og totalt 92% (n=75) av nyreprøvene har et Cd-innhold over 40 mg kg^{-1}. Cd-innholdet i liryper fra Tombstone og Whitehorse, Yukon, er eksepsjonelt høyt og flere fugler har over 50 mg kg^{-1} i lever og over 400 mg kg^{-1} i nyre. Det er allikevel vanskelig å tilskrive disse Cd-nivåene annet enn "naturlig" Cd-forurensning, sannsynligvis gjennom høyt inntak av vier.

På grunnlag av resultatene fra Sverige er det vanskelig å påvise regionale forskjeller, og de fleste lokalitetene har samme Cd-nivå som de mer moderat "forurensede" lokalitetene i Norge. I tidligere undersøkelser av liryper fra midt- og Nord-Sverige ble det funnet lave til moderate Cd-nivå (nyre 30-40 mg kg^{-1}). Vi har ingen lever-prøver med Cd-nivå over 30 mg kg^{-1}, mens 32% (n=38) av prøvene har over 10 mg kg^{-1}. I nyre-prøvene har 93% (n=41) et Cd-nivå over 40 mg kg^{-1}. Dette indikerer en høyere andel av Cd-kontaminerte liryper i denne undersøkelsen sammenlignet med tidligere studier. Som i de andre områdene skyldes forhøyet Cd-nivå sannsynligvis "naturlig" Cd-forurensning gjennom et høyt vierinntak.

Cd-nivået i prøvene fra Russland kan sammenlignes med moderat Cd-kontaminerte lokaliteter i Canada, Norge og Sverige. På grunn av manglende data er det ikke mulig å påvise regionale forskjeller i Cd-nivået. I lever-prøvene har 18% (n=11) et Cd-innhold over 10 mg kg^{-1}, mens 64% (n=11) av nyre-prøvene har over 40 mg kg^{-1}. Igjen er sannsynligvis høyt inntak av vier årsaken til det forhøyede Cd-nivået.

Bly (Pb). Det ble funnet en stor variasjon i Pb-innhold i lever og nyrer fra liryper fra forskjellige lokaliteter i Norge og Canada, men ikke mellom lokaliteter i Sverige og Russland. Nivået som ble funnet i Sverige og Russland er på linje med nivået som ble funnet i Canada og lokaliteter med lavt Pb-nivå fra Norge. Det høyeste nivået totalt sett i alle lokaliteter og land ble funnet i Norge, både for lever og nyre. Høyest Pb-nivå ble funnet i de sørligste lokalitetene i Norge, og dette indikerer en effekt av langtransportert forurensning. I Canada var det signifikant høyere Pb-nivå i vestlige lokaliteter i forhold til lokaliteter i midt-Canada. Om dette gjenspeiler mer forurensning på vest-kysten gjennom langtransport fra mer tettbefolkede områder lengre sør i British Columbia og USA vet vi ikke.

Kvikksølv (Hg). Det ble funnet en tydelig variasjon i Hg-innhold mellom lokaliteter i lever-prøver fra alle land og i nyre-prøver fra alle land untatt Sverige. I Skandinavia ble det ikke funnet noe klart regionalt mønster slik som for Pb. Resultatene fra Canada viste klart høyere Hg-nivå i både lever- og nyre-prøver fra midt-Canada i forhold til vestlige lokaliteter, noe som er motsatt av mønsteret som ble funnet for Cd og Pb.

Kobber (Cu) og sink (Zn). Det ble funnet en signifikant variasjon mellom lokaliteter for begge metaller i så vel lever som nyre i Canada og Norge, mens denne variasjonen bare ble funnet i nyre-prøver fra Sverige. En sammenligning mellom vest- og midt-Canada gir en signifikant forskjell bare for Cu i lever-prøver, og de høyeste verdiene ble funnet i midt-Canada. Det ble ikke funnet noen klare regionale forskjeller verken mellom eller innen land, men det ser allikevel ut som om enkelte lokaliteter i Canada har høyere Cu-nivå i nyre-prøver i forhold til Skandinavia og Russland. Dette er de samme lokalitetene som også har relativt høyt nivå av Cd og Zn i nyrer. Sannsynligvis kan variasjonen som ble funnet for Cu og Zn best forklares som naturlig variasjon i jordsmonnet. Vi kan allikevel ikke utelukke påvirkning fra lokalt eller langtransportert nedfall fra gruver og smelteverk.

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Appendix 1

Metal content in kidneys and liver of individual willow ptarmigan collected at 6 localities in Sweden, 9 in Canada and 2 in Russia. All results given as mg kg dry weight. Ad - adult, juv - juvenile. For Norway see Kålås & Lierhagen (1992). - Metallinnhold i lever og nyre fra individuelle liryper innsamlet fra 6 lokaliteter i Sverige, 9 i Canada og 2 i Russland. Alle resultater er gitt som mg kg tørr vekt. Ad - voksen, juv - ungfugl. For Norge se Kålås & Lierhagen (1992).

Country	Locality	Date	Sex	Age	Cd/kidney	Pb/kidney	Hg/kidney	Cu/kidney	Zn/kidney	J. no.	Cd/liver	Pb/liver	Hg/liver	Cu/liver	Zn/liver
Sverige	Stora Sjøfallet	28.08.94		Ad	63,56	0,858	0,103	16,66	125,11	1106	6,23	0,204	0,013	10,20	76,61
Sverige	Stora Sjøfallet	28.08.94		Ad	104,80	0,934	0,085	18,43	154,55	1107	17,93	0,708	0,013	14,80	108,05
Sverige	Stora Sjøfallet	29.08.94		Ad	0,78	0,386	0,044	13,81	98,98	1108	0,10	0,184	0,022	14,00	95,40
Sverige	Arjeplog	25.09.94		Ad	78,79	0,499	0,109	18,15	133,14	1109	5,20	0,345	0,020	10,62	80,57
Sverige	Arjeplog	25.09.94		Ad	184,80	9,100	0,104	21,70	165,26	1110	10,11	0,844	0,039	12,45	78,68
Sverige	Arjeplog	25.09.94		Ad	98,30	0,691	0,077	20,05	145,01	1111	10,30	0,306	0,032	17,05	107,07
Sverige	Arjeplog	25.09.94		Ad	134,33	0,697	0,084	16,03	154,37	1112	18,46	1,173	0,059	14,17	103,51
Sverige	Arjeplog	25.09.94		Ad	170,70	0,797	0,154	25,40	172,25	1113	24,75	1,063	0,024	14,70	103,22
Sverige	Arjeplog	25.09.94		Ad	89,66	0,832	0,059	15,14	132,19	1114	10,03	1,044	0,045	13,28	88,40
Sverige	Järpen	01.09.94		Ad	67,13	0,512	0,059	17,23	123,70						
Sverige	Järpen	01.09.94		Ad	65,86		0,059	17,09	130,98	909	7,50	0,697	0,023	11,25	96,15
Sverige	Järpen	01.09.94		Ad	23,88	0,162	0,068	15,54	100,19	910	2,51	0,208	0,014	10,49	69,24
Sverige	Järpen	01.09.94		Ad	88,33	0,125	0,052	19,11	126,25	911	6,74	0,308	0,015	9,37	62,90
Sverige	Järpen	01.09.94		Ad	58,81	0,306	0,039	14,08	94,94						
Sverige	Järpen	01.09.94		Ad	31,36		0,092	16,25	108,59	912	2,89	0,280	0,010	12,32	80,97
Sverige	Järpen	01.09.94		Ad	113,62	4,187	0,092	18,56	130,59	913	8,33		0,012	13,74	85,41
Sverige	Järpen	01.09.94		Ad	82,78	0,525	0,098	19,27	129,58	914	9,03	3,983	0,012	14,54	88,52
Sverige	Järpen	01.09.94		Ad	78,75		0,071	16,45	139,56						
Sverige	Järpen	01.09.94		Ad	35,76		0,555	15,74	86,93	915	2,03		0,009	12,31	80,37
Sverige	Vilhelmina	01.09.94		Ad	70,88	0,267	0,060	11,48	106,63	916	8,38	0,321	0,012	11,45	85,85
Sverige	Vilhelmina	01.09.94		Ad	2,98	0,365	0,048	14,39	93,90	917	0,59	0,176	0,009	13,33	84,68
Sverige	Glen	25.08.94	female	Ad	73,85		0,101	16,47	155,78	940	8,98		0,050	13,61	106,73
Sverige	Glen	25.08.94	male	Ad	68,82	0,808	0,090	15,04	122,59	941	9,50	0,529	0,023	15,12	78,58
Sverige	Glen	25.08.94	male	Ad	97,22	2,878	0,123	15,56	126,78	920	8,48	0,487	0,014	14,66	114,99
Sverige	Glen	25.08.94	male	Ad	115,80	0,536	0,037	15,74	140,67	921	13,83	0,321	0,012	15,27	87,97
Sverige	Glen	27.08.94	male	Ad	114,98	1,472	0,069	17,41	141,06	922	13,18	1,056	0,012	13,07	91,89
Sverige	Glen	27.08.94	male	Ad	38,81	0,753	0,055	15,91	114,16	923	3,21	0,717	0,010	13,18	100,21
Sverige	Glen	27.08.94	male	Ad	65,69	4,768	0,062	13,47	127,63	924	7,88	0,479	0,011	12,67	98,05
Sverige	Glen	27.08.94	male	Ad	229,81	1,316	0,073	19,73	168,91	925	12,01	0,523	0,011	11,74	85,40
Sverige	Glen	27.08.94	male	Ad	50,12	0,773	0,062	15,75	117,42	926	4,54	0,352	0,015	10,62	82,08
Sverige	Glen	27.08.94	male	Ad	45,77	0,674	0,097	16,23	119,41	927	2,27	0,681	0,017	11,34	80,51

Country	Locality	Date	Sex	Age	Cd/kidney	Pb/kidney	Hg/kidney	Cu/kidney	Zn/kidney	J. no.	Cd/liver	Pb/liver	Hg/liver	Cu/liver	Zn/liver
Sverige	Gäddede	01.02.95	male	Juv	42,72	0,859	0,143	13,87	130,79	965	16,94	0,964	0,124	15,66	100,85
Sverige	Gäddede	01.02.95		Ad	40,56		0,304	13,05	124,14	966	8,92		0,117	15,23	100,01
Sverige	Gäddede	01.02.95	male	Juv	51,82		0,313	15,27	119,08	967	10,10	1,006	0,125	16,55	104,87
Sverige	Gäddede	01.02.95		Juv	27,42	0,273	0,039	12,40	105,59	968	7,64		0,143	14,38	94,67
Sverige	Gäddede	01.02.95		Juv	37,49	0,374	0,044	15,11	140,18	969	9,79	0,291	0,034	16,89	101,98
Sverige	Gäddede	01.02.95		Ad	86,44	0,608	0,189	11,37	113,21	970	9,73	0,924	0,082	11,09	77,02
Sverige	Gäddede	01.02.95		Ad	28,06	0,779	0,231	12,16	115,35	971	6,03	0,931	0,206	12,50	84,56
Sverige	Gäddede	01.02.95	female	Ad	43,01	0,623	0,208	12,24	129,40	972	11,27	0,539	0,088	12,54	85,51
Sverige	Gäddede	01.02.95			47,84	0,563	0,062	16,54	116,77	973	5,53	0,307	0,015	12,12	70,40
Sverige	Gäddede	01.02.95		Ad	80,89	1,799	0,233	19,72	174,24	974	9,18	0,662	0,024	13,49	125,13
Canada	Chilkat Pass	21.04.85	male	Ad	88,00	0,207	0,090	22,25	148,31	880	23,49	0,580	0,037	15,59	98,32
Canada	Chilkat Pass	21.05.87	male	Ad	180,34		0,139	28,46	205,05	881	30,31	0,688	0,061	12,98	101,80
Canada	Chilkat Pass	24.05.86	male	Ad	196,10	0,458	0,121	25,14	218,27	882	24,96	0,115	0,022	12,57	113,78
Canada	Chilkat Pass	13.05.87	male	Ad	111,91		0,317	32,58	148,61	883	19,34	0,114	0,050	12,19	86,07
Canada	Chilkat Pass	24.05.86	male	Ad	121,72	0,840	0,110	20,02	189,28	884	46,34	0,132	0,041	13,74	127,73
Canada	Chilkat Pass	09.05.86	female	Ad	169,38	0,319	0,136	23,05	176,70	885	32,03	0,100	0,021	13,84	96,30
Canada	Chilkat Pass	05.03.88	male	Ad	139,25	0,281	0,107	18,78	167,83	886	34,05	0,100	0,066	17,62	106,63
Canada	Chilkat Pass	25.04.87	female	Ad	263,67	0,605	0,220	54,97	187,92	887	50,37	0,370	0,123	147,24	187,62
Canada	Chilkat Pass				110,20	0,285	0,069	13,44	123,49	888	17,07	0,100	0,034	9,45	70,91
Canada	Chilkat Pass	05.03.88		Ad	87,35	0,666	0,108	17,28	155,81	889	35,20	0,259	0,046	18,92	125,81
Canada	Chilkat Pass	01.05.87	female	Ad	76,06	1,195	0,116	18,44	143,56	890	21,41	0,188	0,033	15,47	101,34
Canada	Chilkat Pass	04.05.87	female	Ad	111,96	1,965	0,182	21,08	118,18	891	15,81		0,025	12,67	91,72
Canada	Chilkat Pass	01.05.87	female	Ad	99,49	0,512	0,093	18,61	142,48	892	21,67	0,283	0,032	12,82	89,38
Canada	Chilkat Pass	26.04.87	female	Ad	114,72	2,390	0,108	19,87	154,51	893	26,38	0,180	0,044	14,33	98,82
Canada	Chilkat Pass	05.05.87	male	Juv	196,10	0,762	0,156	25,03	164,50	894	31,91	0,304	0,029	13,18	108,33
Canada	Chilkat Pass	01.05.87	female	Ad	121,88	0,879	0,108	17,84	181,93	895	32,47	0,150	0,044	13,51	109,60
Canada	Chilkat Pass	01.05.87	female	Ad	120,77	0,278	0,132	18,64	148,26	896	22,27	0,242	0,039	13,72	107,02
Canada	Chilkat Pass	28.04.87	female	Ad	177,85	1,624	0,134	21,99	173,87	897	24,25		0,054	13,06	105,98
Canada	Chilkat Pass	08.02.88	male	Ad	125,95	4,725	0,061	19,37	153,38	898	33,26	8,570	0,026	14,56	98,57
Canada	Chilkat Pass	14.02.88	male	Ad	370,47	0,525	0,174	31,61	226,18	899	32,27	0,385	0,057	16,92	124,00
Canada	Chilkat Pass	14.02.88	female	Ad	166,83		0,096	22,38	159,41	900	43,55	0,905	0,037	18,47	103,14
Canada	Chilkat Pass	14.02.88	male	Ad	169,46	0,235	0,154	26,38	178,85	901	23,76	0,100	0,028	14,01	97,55
Canada	Chilkat Pass	01.12.87	female	Juv	37,15	0,549	0,069	15,27	112,33	902	10,48	0,253	0,019	13,23	116,81
Canada	Chilkat Pass	05.03.88		Ad	104,67	0,299	0,102	17,70	154,83	903	17,50	0,100	0,035	15,97	106,93
Canada	Chilkat Pass	08.02.88		Ad	138,56		0,117	17,62	138,78	904	29,48		0,055	13,17	126,79
Canada	Chilkat Pass	12.12.87	male	Ad	109,37		0,315	20,14	131,90	905	13,84	0,100	0,017	13,19	94,73
Canada	Chilkat Pass	12.12.87	male	Ad	302,81	0,284	0,052	24,90	172,32	906	36,76	0,493	0,022	16,39	150,68

Country	Locality	Date	Sex	Age	Cd/kidney	Pb/kidney	Hg/kidney	Cu/kidney	Zn/kidney	J. no.	Cd/liver	Pb/liver	Hg/liver	Cu/liver	Zn/liver
Canada	Chilkat Pass	08.02.88	female	Ad	66,12	0,265	0,059	15,90	130,63	907	27,22	1,243	0,032	13,23	104,60
Canada	Chilkat Pass	08.02.88	male	Ad	194,57	3,122	0,086	22,27	159,22	908	45,33	0,247	0,031	15,75	114,95
Canada	Buchans	21.10.92	female	Ad	53,72	0,103	0,255	16,92	135,34	1049	5,60	0,479	0,030	12,76	87,75
Canada	Buchans	21.10.92	male	Ad	31,07		0,225	51,84	156,34	1050	7,18	0,815	0,043	16,29	94,39
Canada	Yellowknife	28.01.93	male	Ad	280,10	3,194	0,343	31,02	260,37	1051	9,22	0,096	0,079	16,40	102,48
Canada	Yellowknife	28.01.93	male	Ad	32,65	0,210	0,181	17,21	116,67	1052	36,26	0,100	0,144	20,34	139,48
Canada	Yellowknife	28.01.93	female	Ad	253,06	0,127	0,225	33,77	268,39	1053	9,84	0,100	0,101	22,69	110,82
Canada	Yellowknife	28.01.93	male	Ad	42,33	0,194	0,134	14,53	115,75	1054	29,54	0,100	0,210	17,75	124,01
Canada	Yellowknife	28.01.93	male	Ad	53,09	0,809	0,122	12,49	107,60	1055	6,97	0,100	0,070	17,61	108,35
Canada	Yellowknife	28.01.93	female	Ad	88,29	1,109	0,156	19,41	145,01	1056	10,53	0,096	0,165	21,83	130,53
Canada	Yellowknife	28.01.93	female	Ad	130,31	0,633	0,162	21,45	168,21	1057	21,60	0,181	0,080	17,97	116,78
Canada	Yellowknife	28.01.93	female	Ad	48,07	0,215	0,218	23,01	162,52	1058	10,12	0,100	0,070	19,82	113,86
Canada	Yellowknife	28.01.93	male	Ad	51,18	0,178	0,140	18,08	134,95	1059	9,19	0,183	0,063	12,85	93,59
Canada	Yellowknife	28.01.93	male	Ad	52,53	0,251	0,168	17,33	143,68	1060	11,64	0,114	0,140	17,84	105,67
Canada	Rich. River	28.05.93	female	Ad	127,44		0,226	17,20	141,04	1061	40,82	0,100	0,074	16,34	119,05
Canada	Rich. River	28.05.93	female	Ad	215,00	0,213	0,208	26,95	173,00	1062	50,15	0,103	0,074	16,80	127,72
Canada	Rich. River	28.05.93	female	Ad	120,75	0,140	0,431	17,81	131,54	1063	13,94	0,100	0,094	14,21	98,00
Canada	Rich. River	28.05.93	male	Ad	48,21	1,615	0,969	19,66	146,15	1064	8,77	1,496	0,081	14,78	90,74
Canada	Rich. River	28.05.93	male	Ad	100,64	0,364	0,757	23,40	155,73	1065	12,88	0,356	0,130	16,20	101,84
Canada	Rich. River	28.05.93	male	Ad	170,12	0,407	1,492	25,97	192,10	1066	28,50	0,102	0,374	20,77	202,91
Canada	Rich. River	28.05.93	male	Ad	113,23	0,836	1,380	20,44	163,70	1067	10,63	0,100	0,166	14,89	99,42
Canada	Rich. River	28.05.93	male	Ad	92,65	0,206	0,630	17,32	130,35	1068	12,52	0,190	0,268	13,13	100,16
Canada	Rich. River	28.05.93	male	Ad	102,01	0,283	0,481	21,32	142,83	1069	13,49	0,403	0,096	15,11	99,96
Canada	Rich. River	28.05.93	male	Ad	90,88	6,200	0,881	18,78	149,98	1070	13,73	0,207	0,102	14,72	101,23
Canada	Baker Lake	01.06.93	male	Ad	307,72	0,105	0,300	29,81	237,11	1071	46,08	0,100	0,069	15,48	105,89
Canada	Baker Lake	01.06.93	female	Ad	174,28	0,104	0,239	28,72	165,44	1072	20,45	0,100	0,063	11,74	85,60
Canada	Baker Lake	01.06.93	male	Ad	367,13	0,129	0,542	27,02	233,98	1073	40,42	0,100	0,172	20,36	103,83
Canada	Baker Lake	01.06.93	female	Ad	143,54	0,125	0,154	21,37	153,24	1074	17,67	0,100	0,050	13,69	94,45
Canada	Baker Lake	02.06.93	female	Ad	154,20	0,333	0,245	28,03	173,90	1075	13,34	0,100	0,045	12,53	94,10
Canada	Chick Lake	07.12.93	male	Ad	17,01	0,100	0,025	15,23	132,23	1076	2,96	0,097	0,013	17,76	99,97
Canada	Chick Lake	07.12.93	female	Ad	62,60	9,600	0,166	19,10	168,11	1077	16,19	0,219	0,072	24,74	157,74
Canada	Chick Lake	07.12.93	female	Ad	34,60	0,102	0,156	16,75	145,68	1078	7,79	0,100	0,087	23,62	143,99
Canada	Chick Lake	07.12.93	female	Ad	35,74	0,105	0,125	17,83	135,62	1079	7,58	0,100	0,041	19,22	109,64
Canada	Chick Lake	07.12.93	female	Ad	43,63	0,140	0,113	15,09	146,80	1080	8,93	0,122	0,054	16,29	104,35
Canada	Chick Lake	07.12.93	female	Ad	45,54	0,419	0,191	18,23	163,70	1081	11,84	0,397	0,073	16,31	114,73
Canada	Chick Lake	07.12.93	female	Ad	41,56	0,096	0,146	16,16	142,51	1082	9,87	0,100	0,138	18,40	103,98
Canada	Chick Lake	07.12.93	female	Ad	216,58	0,100	0,110	20,91	162,87	1083	21,45	0,100	0,044	25,98	115,75
Canada	Tombstone	30.04.94	male	Ad	462,71	0,551	0,195	35,44	205,23	1084	63,21	0,100	0,048	12,30	87,68

Country	Locality	Date	Sex	Age	Cd/kidney	Pb/kidney	Hg/kidney	Cu/kidney	Zn/kidney	J. no.	Cd/liver	Pb/liver	Hg/liver	Cu/liver	Zn/liver
Canada	Tombstone	30.04.94	female	Ad	481,11	0,360	0,107	33,21	217,18	1085	43,42	0,100	0,030	11,61	102,29
Canada	Whitehorse	10.07.94	female	Ad	843,62	2,388	0,092	59,50	275,99	1086	83,70	0,120	0,038	19,40	147,86
Canada	Whitehorse	20.06.94	male	Ad	527,83	0,179	0,188	31,12	243,94	1087	80,80	0,100	0,027	14,21	158,91
Canada	Whitehorse	13.06.94	male	Ad	728,73	0,538	0,102	59,92	257,20	1088	88,09		0,028	15,44	128,33
Canada	Whitehorse	01.08.94	female	Ad	299,31	0,678	0,137	23,56	208,31	1089	36,45	0,100	0,036	13,23	130,64
Canada	Whitehorse	10.07.94	male	Ad	219,87	0,219	0,079	22,27	197,49	1090	29,39	0,100	0,005	13,85	117,41
Canada	Old Crow	01.12.94	female	Ad	149,21	0,622	0,154	23,57	0,00	1091	25,98	0,317	0,060	16,89	108,66
Canada	Old Crow	01.12.94	female	Ad	81,87	1,075	0,116	17,86	156,23	1092	23,94	0,153	0,061	16,34	116,86
Canada	Old Crow	01.12.94	female	Ad	99,46	0,201	0,093	24,41	169,79	1093	21,43	0,105	0,031	15,06	105,75
Canada	Old Crow	01.12.94	female	Ad	83,76	0,284	0,110	18,27	142,13	1094	17,54	0,185	0,060	15,35	99,36
Russland	Sendasko	14.04.95	male		74,16	0,442	0,095	32,37	192,04	1095	10,19	0,100	0,027	13,58	54,52
Russland	Sendasko	14.04.95	male		59,25	0,338	0,059	21,97	215,19	1096	5,75	0,100	0,028	13,36	72,76
Russland	Sendasko	14.04.95			40,11	0,595	0,046	18,63	154,14	1097	4,72	0,318	0,027	17,97	87,18
Russland	Sendasko	14.04.95	female		37,64	1,008	0,023	15,10	126,90	1098	3,75	0,462	0,029	15,63	78,60
Russland	Sendasko	14.04.95			26,32	0,384	0,053	25,14	154,31	1099	6,58	0,176	0,041	18,06	100,56
Russland	Sendasko	14.04.95	female		49,53	0,656	0,050	19,10	149,02	1100	7,56	0,146	0,031	18,53	91,51
Russland	Noboridnova	03.05.95			18,09	0,683	0,080	15,81	128,16	1101	4,73	0,106	0,055	14,97	102,89
Russland	Noboridnova	03.05.95			71,41	0,521	0,102	16,05	166,97	1102	9,02	0,306	0,099	14,38	106,73
Russland	Noboridnova	03.05.95			74,98	0,556	0,080	22,23	181,42	1103	12,02	0,776	0,051	35,62	91,45
Russland	Noboridnova	03.05.95			86,46	0,359	0,099	19,72	160,63	1104	6,03	0,179	0,033	10,22	61,21
Russland	Noboridnova	03.05.95			31,92	0,599	0,068	17,01	155,93	1105	3,47	0,531	0,045	15,28	85,63

Appendix 2

Median metal content and interquartile range by locality in willow ptarmigan liver. Values given as mg kg^{-1} dry weight. - Metallinnhold i lever fra liryper gitt som median og interkvartil spredning for hver lokalitet. Alle resultater er gitt som mg kg^{-1} tørr vekt.

		Cd		Pb		Hg		Cu		Zn	
Country	**Locality**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**
NORWAY											
1	Lund	5,32	2,15	4,240	2,508	0,046	0,027	11,70	3,00	85,00	28,00
2	Bykle	11,52	13,27	2,720	2,235	0,084	0,028	10,30	1,38	89,00	18,75
3	Eidfjord	16,50	11,12	0,370	0,090	0,017	0,003	12,90	1,50	103,00	5,00
4	Hemsedal	6,46	1,65	2,290	0,360	0,040	0,011	9,30	2,70	106,00	32,00
5	Kongsvoll	10,84	7,24	0,455	0,625	0,036	0,024	12,15	3,28	96,50	12,75
6	Eikesdal	3,03	0,66	0,160	0,140	0,030	0,003	10,40	1,30	69,00	7,00
7	Rindal	4,15	3,23	0,945	0,793	0,035	0,034	12,90	1,35	83,50	12,50
8	Selbu	4,32	2,74	0,820	0,410	0,036	0,020	13,65	1,93	84,00	13,75
9	Lierne	7,48	1,65	0,650	0,890	0,028	0,014	11,60	3,00	79,00	8,00
10	Øksnes	4,64	2,61	0,950	0,750	0,020	0,001	12,15	1,65	86,50	7,75
11	Dividalen	11,11	4,09	0,720	0,520	0,019	0,002	13,00	1,10	90,00	12,00
12	Kautokeino	11,75	1,71	0,270	0,293	0,037	0,025	11,90	1,80	71,00	9,00
13	Porsanger	3,10	4,28	0,360	5,120	0,022	0,008	12,00	0,90	92,00	35,00
14	Skallelv	4,93	5,18	1,470	1,280	0,032	0,010	13,30	2,70	87,00	3,00
15	Jarfjord	10,23	6,80	0,810	0,510	0,038	0,013	13,40	1,10	81,50	3,00
SWEDEN											
1	Järpen	6,74	5,22	0,308	0,417	0,012	0,004	12,31	2,16	80,97	12,16
2	Vilhelmina	4,49	3,90	0,249	0,073	0,011	0,002	12,39	0,94	85,27	0,59
3	Glen	8,73	6,00	0,523	0,201	0,013	0,005	13,12	2,43	89,93	16,76
4	Gäddede	9,45	2,06	0,793	0,458	0,103	0,079	13,94	3,04	97,34	16,90
5	Arjeplog	10,21	6,37	0,944	0,588	0,035	0,017	13,73	1,91	95,81	20,91
6	Stora Sjøfallet	6,23	8,92	0,204	0,262	0,013	0,004	14,00	2,30	95,40	15,72
CANADA											
1	Chilkat Pass	27,22	11,59	0,245	0,267	0,035	0,018	13,74	2,58	105,98	16,63
2	Buchans	6,39	0,79	0,647	0,168	0,037	0,007	14,52	1,77	91,07	3,32
3	Yellowknife	10,32	9,73	0,100	0,010	0,090	0,070	17,91	2,56	112,34	15,86
4	Richardson RIver	13,61	12,25	0,146	0,218	0,099	0,073	15,00	1,57	100,70	15,20
5	Baker Lake	20,45	22,75	0,100	0,000	0,063	0,019	13,69	2,96	94,45	9,73
6	Chick Lake	9,40	5,19	0,100	0,046	0,063	0,033	18,81	6,50	112,19	18,55

		Cd		Pb		Hg		Cu		Zn	
Country	**Locality**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**
7	Tombstone	53,32	9,89	0,100	0,000	0,039	0,009	11,96	0,35	94,99	7,30
8	Whitehorse	80,80	47,25	0,100	0,005	0,028	0,009	14,21	1,59	130,64	19,53
9	Old Crow	22,68	3,99	0,169	0,077	0,060	0,008	15,84	1,20	107,21	6,56
RUSSIA											
1	Sendasko	6,17	2,33	0,161	0,171	0,029	0,003	16,80	3,95	82,89	16,21
2	Noboridnova	6,03	4,29	0,306	0,352	0,051	0,010	14,97	0,90	91,45	17,26

Appendix 3

Median metal content and interquartile range by locality in willow ptarmigan kidney. Values given as mg kg^{-1} dry weight. - Metallinnhold i nyre fra liryper gitt som median og interkvartil spredning for hver lokalitet. Alle resultater er gitt som mg kg $^{-1}$ tørr vekt.

		Cd		Pb		Hg		Cu		Zn	
Country	**Locality**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**
NORWAY											
1	Lund	33,20	9,92	5,240	3,473	0,220	0,066	14,00	4,90	130,00	19,00
2	Bykle	62,83	82,43	3,485	1,848	0,176	0,017	6,90	1,40	103,00	31,50
3	Eidfjord	228,06	154,29	1,180	0,115	0,114	0,064	20,15	9,98	189,00	57,50
4	Hemsedal	75,92	60,43	2,990	0,840	0,155	0,023	14,10	1,80	139,00	12,00
5	Kongsvoll	129,66	44,61	0,800	0,215	0,055	0,035	18,55	2,43	145,00	23,75
6	Eikesdal		0,00		0,000		0,000		0,00		0,00
7	Rindal	27,12	18,59	1,570	0,550	0,130	0,045	13,30	2,65	96,00	27,00
8	Selbu	52,83	21,05	0,480	0,060	0,074	0,052	12,80	2,00	119,00	13,00
9	Lierne	54,28	13,52	0,620	0,260	0,100	0,101	12,10	4,90	120,00	10,00
10	Øksnes	54,98	48,20	0,600	0,465	0,074	0,025	9,45	1,73	128,00	26,25
11	Dividalen	143,30	63,09	0,320	0,225	0,086	0,030	15,70	1,00	156,00	8,00
12	Kautokeino	139,08	30,51	1,590	0,610	0,190	0,070	20,90	4,10	137,00	22,00
13	Porsanger	71,10	20,30	0,150	0,000	0,046	0,019	14,20	1,20	107,00	8,00
14	Skallelv	87,90	38,50	0,810	0,700	0,077	0,019	16,00	1,10	110,00	12,00
15	Jarfjord	126,90	30,90	0,450	0,180	0,099	0,018	17,30	2,40	118,00	5,00
SWEDEN											
1	Järpen	66,49	40,25	0,409	0,324	0,070	0,033	16,77	2,36	124,97	28,04
2	Vilhelmina	36,93	33,95	0,316	0,049	0,054	0,006	12,94	1,46	100,26	6,36
3	Glen	71,34	56,53	0,808	0,719	0,071	0,034	15,83	0,80	127,20	20,76
4	Gäddede	42,86	12,57	0,616	0,283	0,198	0,150	13,46	2,95	121,61	14,74
5	Arjeplog	116,31	69,79	0,747	0,130	0,094	0,029	19,10	4,73	149,69	26,44
6	Stora Sjøfallet	63,56	52,01	0,858	0,274	0,085	0,030	16,66	2,31	125,11	27,78
CANADA											
1	Chilkat Pass	121,88	68,48	0,537	0,673	0,110	0,046	20,14	6,46	155,81	33,13
2	Buchans	42,40	11,33	0,103	0,000	0,240	0,015	34,38	17,46	145,84	10,50
3	Yellowknife	52,81	70,96	0,233	0,567	0,165	0,064	18,74	5,38	144,35	45,55
4	Richardson RIver	107,62	31,12	0,364	0,623	0,693	0,504	20,05	4,82	148,06	20,21
5	Baker Lake	174,28	153,52	0,125	0,025	0,245	0,061	28,03	1,70	173,90	68,54
6	Chick Lake	42,59	14,35	0,103	0,110	0,135	0,046	17,29	2,52	146,24	22,29

		Cd		Pb		Hg		Cu		Zn	
Country	**Locality**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**	**Median**	**Q_3-Q_1**
7	Tombstone	471,91	9,20	0,456	0,095	0,151	0,044	34,32	1,11	211,20	5,98
8	Whitehorse	527,83	429,42	0,538	0,458	0,102	0,045	31,12	35,94	243,94	48,89
9	Old Crow	91,61	28,61	0,453	0,472	0,113	0,020	20,92	5,61	149,18	53,02
RUSSIA											
1	Sendasko	44,82	18,57	0,518	0,242	0,051	0,011	20,54	5,60	154,23	32,31
2	Noboridnova	71,41	43,06	0,556	0,077	0,080	0,019	17,01	3,67	160,63	11,04

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Henvendelser vedrørende rapportene rettes til utførende institusjoner.

NINA Oppdragsmelding 646

ISSN 0802-4103
ISBN 82-426-1134-3

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